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PREFACE TO No. XII.

THE paper on *The Hastings' Shoal,* and the concluding paper on *The Great Trigonometrical Survey,* will appear in the next number.

I have received several valuable papers lately, which shall have due insertion as I can find room for them.

I have inserted a paper of my own this time, (thereby keeping out, I am sure, a much more valuable one by some one else,) but it is with the view stated in the Preface to the last Number, of inducing others to note down the chief Engineering characteristics of their districts, by which a mass of interesting and often valuable information would be collected, which the writers might otherwise be disinclined to communicate, from not having any *particular* work of importance to write about. Stray notes of this kind, however crudely put together as to style, are generally valuable from being the results of practical experience.

The Frontispiece given with the present number is an illustration of the new and valuable art of Photo-zincography, now being carried out with much success in the Surveyor General's Office at Dehra Doon. In its application to Mapping, its utility can scarcely be over-rated, and I hope to give a specimen of this branch of the art in the next number.

I see that English Editors are not more scrupulous than some of their Indian brethren, the *Civil Engineer and Architect's Journal* having been good enough to re-print two long articles from these papers, without the smallest attempt at acknowledgment.

J. G. M.

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VENTILATION AND COOLING*

In 1862, as our readers are probably aware, a Royal Commission was constituted in England, to Report on the state and defects of the Barrack and Hospital accommodation provided for the army, and to suggest measures for its improvement. Its Report was presented in the following year; and in 1864 a Supplementary Report was issued, containing suggestions for the Sanitary improvement of Indian stations, with special reference to the construction of Barracks and Hospitals in tropical climates. In 1863, the Government of India appointed Lieut.-Colonel W. A. Crommelin, C.B., R.E., an officer of much Civil and Military experience, to take up the matter locally, and with special attention to Indian requirements, and the important resolution of the Governor General in Council in the P. W. Department, dated 16th December, 1864, gives the final result of that Officer's labors for the last two years.

Although, however, the details of arrangement and construction of Barracks and Hospitals were thus practically settled after very full discussion, it was felt that the question of Ventilating and Cooling Barracks and other public buildings in India might, with advantage, be considered by a separate Committee, which was duly constituted at Roorkee in 1865; and their First Report has lately been presented. Although it is chiefly occupied by preliminary discussions necessary to clear the ground for useful results being arrived at, it sufficiently indicates the probable issue of the enquiry to make it worth while to state briefly the difficulties attending the subject, and the points to which inventors' attention should be directed in their endeavour to solve those difficulties.

---

* First Report of the Committee on Ventilation and Cooling of Public Buildings in India. Roorkee, 1866.

The Ventilation of buildings in cold or temperate climates, depends on the fact of the air inside a building being warmer and therefore lighter than the external air. If holes are left in the upper part of a room, the foul air will pass out of them and fresh air can come in through the windows or otherwise. If more powerful means are required, then regular ventilating shafts are provided, by one set of which the cold air comes in, and by the other set the foul air escapes. The up-cast and down-cast shafts of mines are arranged as is well known on this principle, and half the modern public buildings are ventilated in the same way—the heat of a fire or gas being used in the up-shafts to create a strong draft.

But in a great part of India, the temperature of the external air is very much higher than that inside a building; and that often for months together, and by night as well as by day. This fact appears to have been lost sight of by the London Commissioners on Tropical Barracks, their most important recommendations being evidently adapted only to a West Indian climate, or the climate of India near the sea-coast, and not to Upper India and its hot winds at all. Indeed, they acknowledge the difficulties on this point, and recommend its being locally taken up, as it has been. It is evident, from a little consideration, that the above fact prevents anything like self-acting ventilation, for doors and windows must be shut to exclude the hot air, while the foul air inside being cooler and therefore heavier, will not of its own accord pass out of openings above. To effect the admission of the one and the exit of the other, it will be necessary to create a powerful artificial draft.

But for some portion of the hot weather (as said above) it is necessary to cool the air previous to admitting it, and the two questions have to a certain extent to be considered together. What is now done, as is well known, is either to keep doors and windows shut all day long, an unhealthy practice where a number of men are in the same building, or to put a *tattie*, or grass screen in the doorways to windward, keep it wetted, and thus cool the hot air as it passes throught it—the temperature being lowered in this manner from 5° to 20°, varying with the heat and dryness of the blast.

The defects of this practice are several,—unless there is a strong wind blowing, very little air comes in through the *tattie*,—and if the wind *is* strong, it passes into the room in cold damp blasts, unhealthy to those who are near it, while at the further end of the room it may be scarcely felt. Unless the *tattie* is kept constantly wet, of course hot air, instead of cold, is drawn in, and it is difficult to keep the *tattie* properly wet by hand-labor alone. Moreover, the arrangement is only effective on the windward side of the building; the rooms to leeward must remain hot. The vegetable matter of the *tattie* under the constant influence of heat and moisture is also apt to decompose, and render the permeating air unwholesome.

Attempts have been made to remedy these evils. Grant's trough apparatus ensures a more equable watering of the tattie—and thermantidotes, consisting of an arrangement of blowers turning on a horizontal axle, and driven by hand or bullock-power, are used to create a blast when the wind is not blowing. There still remains however the fitful character of the blast, and the want of any means of diffusing it equably.

It may be as well here to note in passing, that Punkahs merely agitate the hot air inside, and though rendering it for the moment cool to those under or near them, do not at all lower the general temperature of a room, nor do they help at all in ventilating it. We shall speak of their arrangement presently,—but their expense and inconvenience make it very desirable to supersede them altogether, if possible.

More than one scheme has been proposed for cooling the air without the aid of the tattie, and it is possible that some of these may be effectual, but inventors are apt to forget the large quantity of cool air required—and the expense attending the arrangement. Nor will a complicated apparatus do for a country where unskilled workmen are alone available to repair it when anything goes wrong. One inventor, for instance, proposes to force the air through ice, but makes no calculation of the enormous expense to be incurred in making the ice. A more feasible proposal is that of Professor Piazzi Smith, viz., to force the air through a worm like that of a still, surrounded by cold water; the air when thus cooled to be distributed as required—but the power required to overcome the great friction of the hollow tubes, and to provide an adequate supply of air, seems to be have been under-rated; a scheme on the same principle as this, but differing in detail, is still under consideration. Of the various kind of blowers, other than the ordinary thermantidote, which have been tried or suggested, Arnott's Hydrostatic Pump is the only one that promises well, and seems at all likely to succeed.

From all the discussion that has taken place, and with the numerous projects submitted, the results at present attained appear to be these:—

1*st.* That no arrangement as yet hit upon for cooling the air is better than the grass tattie; and that some better means for watering it is still desirable.

2*nd.* That during the rainy season it is not necessary to cool the air artificially, but simply to blow in a proper quantity of it.

3*rd.* That as a blower, nothing has yet appeared,* preferable to one or other of the forms of the ordinary thermantidote, driven by coolies or bullocks, or in particular places by steam power.

4*th.* That the amount of fresh air required has been estimated by the English Commission as 20 cubic feet per man per minute, and this may be taken as the standard. The provision for any particular building therefore, is a simple matter of calculation, depending on its size, number of inmates, number of thermantidotes used, and the speed at which they are driven.

5*th.* That the proper mode of diffusing the fresh air is still an open question; probably it should be by flues from the thermantidote chamber, but whether under the floor or round the sides of the room; whether one or two large inlets will be best for a room; or whether a number of small inlets is preferable, are still undecided points, and can only be settled by experiment.

---

* Unless Arnott's pump on the gasometer principle, which is still under trial, should prove effective and economical.

6th. That from recent experiments which have been made, the position (as regards height) of the outlets for foul air is a matter of indifference. It will be forced out, wherever the exits are placed, if a proper supply of fresh air is forced in.

If it should eventually turn out, that in many buildings at any rate, Punkahs cannot be dispensed with, the best mode of pulling them with due regard to efficiency and economy has still to be decided. Grant's system of treadles, which promised well at first, seems latterly to have failed. Rotary punkahs have been several times proposed and rejected, and schemes of pulling punkahs by clockwork—by pendulums—and by falling weights, seem as yet not to have passed out of the regions of theory. It seems generally admitted now, that the old broad punkahs with short light fringes are far less effective than narrow punkahs with deep heavy fringes; and if their number is properly accomodated to the size of the room—and the pulling power to the number to be pulled—and if they are carefully hung, it does not seem likely from such evidence as has yet appeared, that the present arrangement will be in principle superseded.

The above remarks on an important question may be of use to many whose attention has been, and is now turned in this direction, as serving to show how the question at present stands, and what more is wanted. It is quite possible, however, that they may be modified by the time the next Report of the Ventilation Committee may be presented, and they are merely an expression of individual views.

J. G. M.

No. CXI.

THE ADEN TANKS.

Compiled from an account of Aden by Captain Playfair, *and from Official Records, by* Lieut. S. S. Jacob, *Assist. Engineer.*

The scarcity of water supply must always have been a cause of anxiety to those who have from time to time inhabited Aden. Water of a good quality, but in limited quantities, is found at the head of valleys within the crater and to the west of the town; as the wells approach the sea, they become more and more brackish, and those within the town are unfit for any purpose save ablution. These are in number about 150, of which perhaps 50 are potable, and yield an aggregate quantity of about 15,000 gallons per diem. They are sunk often in the solid rock to a depth of from 120 to 185 feet, and in the best one, the water stands at a depth of 70 feet below the sea level. An abundant supply of water is procurable on the northern side of the harbour but the difficulty of bringing it into Aden and its liability to be cut off by hostile Arabs, have hitherto rendered it almost unavailable. So great has been the demand, that the brackish water brought from Sheik Othman, a village five miles distant, has often been sold to the shipping and others, for as much as Rs. 8 per 100 gallons.

A project for bringing fresh water from the interior by an aqueduct is now under the consideration of Government.

It was doubtless the want of this common necessary of life which induced the first inhabitants to provide some means of storing supplies of water, and the features of the rocks were well adapted to suggest the construction of Reservoirs or Tanks.

In the centre of the Peninsula of Aden is a range of hills, which rises almost perpendicularly to a height of 1,760 feet, and forms the wall of the crater of Aden. On the western side the hills are very precipitous, and the rain water descending from them is rapidly carried to the sea by means of long narrow valleys. On the interior or eastern side the hills are quite as abrupt, but the descent is broken by a large table land occurring midway between the summit and the sea level, which occupies about one-fifth of the entire superficies of Aden. This plateau is intersected by numerous ravines, nearly all of which converge into one valley, which thus receives a large portion of the drainage of the peninsula. The steepness of the hills, the hardness of the rocks, and the scanty soil upon them, all combine to prevent any great amount of absorption; and thus a moderate fall of rain suffices to send a stupendous torrent of water down the valley, which ere it reaches the sea not unfrequently attains the proportions of a river.

To collect and store this water the Reservoirs were constructed. They are extremely fantastic in their shapes; some are formed by a dyke being built across the gorge of a valley; in others the soil in front of a re-entering angle in the hill has been removed, and a salient angle or curve of masonry built in front of it; while every feature of the adjacent rocks has been taken advantage of, and connected by small masonry channels to ensure no water being lost. The overflow of one tank has been conducted into the succeeding one, and thus a complete chain has been formed.

There is a tradition in Aden, that about A. H. 906 (A. D. 1500) the individual who was then Governor persevered in digging wells for sweet water, and being successful the reservoirs were permitted to fall to ruins, or to be filled up with the débris washed down from the hills, which would be sure to happen sooner or later, as there were no shield bunds; and in 1859, when the tanks were in process of restoration, although the channel had been cleared for about a quarter of a mile above the upper tank, a storm which occurred brought down such a large deposit of stones and gravel, that Captain Fuller in 1860 constructed shield bunds across the necks of the water-courses leading to the tanks. Below the shield bunds, and in addition to them across the main ravine, are two bunds which form lakes, and these are connected with the tanks below, by pipes which can be shut off when necessary.

In the shield bunds are inserted grated sluices 2 feet square, to allow water to pass when it rains but slightly, and before it has time to be absorbed by the rock.

In 1854, Captain Playfair, Assistant to the Political Resident, turned his attention to these tanks, and on his own responsibility undertook the task of restoring them; the expense being met by the Municipal Fund, and by the money realized by the sale of water. A few ruined tanks on the sides of the hills which never were buried or concealed, were the only visible remains of the ancient reservoirs; but as the work progressed, the magnitude of the system became apparent, and a further measure of assistance was afforded to Captain Playfair by the quit rents charged on building grants, being appropriated to the object.

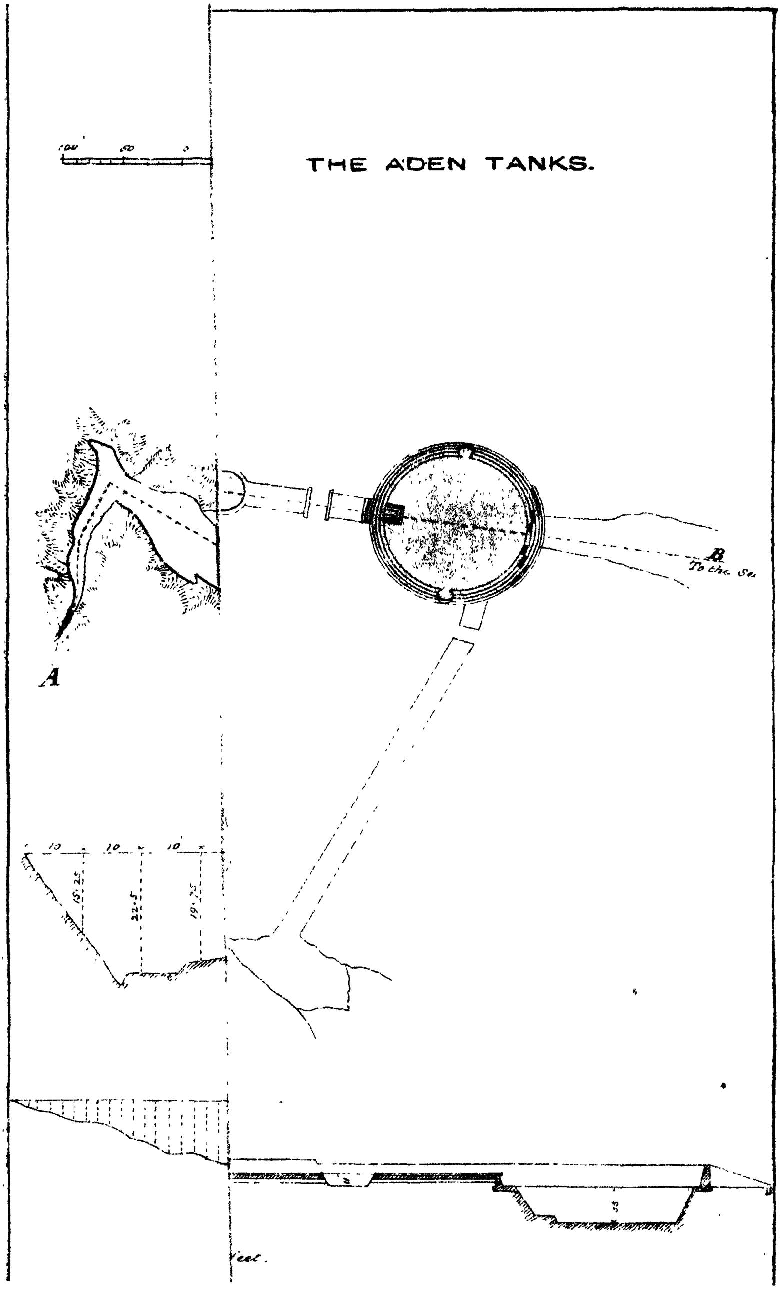
Subsequently, at the request of Brigadier Coghlan, then Political Resident at Aden, Government granted such sums of money as from time to time were required to carry on the restoration without further reference. Each month, as further excavations were made, and the débris with which they were filled was removed, new tanks came to view, and so the work progressed under the Superintendence of Captain Playfair till February 1857, when illness compelled him to return to Europe, and the work was made over to the Executive Engineer, Aden. Up to that time, tanks had been completed, the aggregate capacity of which amounted to about 3,538,000 gallons, and the expense incurred in effecting this, amounted to no more than Rs. 11,542, of which Rs. 6,500 had been granted by Government.

Subsequently, when a violent fall of rain had afforded the necessary experience regarding the style of work required, and the size of the aqueduct necessary to carry of the overflow of No. 1 Tank; Captain Playfair's aqueduct was replaced by one better adapted to resist the immense force exerted by the stream; the walls of the tanks repaired and cleared out by him were also heightened so as to double their capacity, and one tank was greatly increased by using it as a quarry for stone required in the work.

The plan will show the position of the tanks with reference to each other, and the sections will show the depths on the section line; but the bottom of each tank presents more or less an irregular, fantastic appearance, according as the natural surface of the rock has been plastered over, or masonry has been used.

Each tank is connected with the succeeding one by an open or covered duct, and as soon as one is full the water is conducted to supply the next tank, until the whole system is full; and when the last, a large circular

THE ADEN TANKS.



tank, has received its supply, the surplus water is carried to the sea by a channel 60 feet wide, the sides of which are dry rubble (slope 1 to 1) with a masonry coping; and across it at every 30 feet masonry bunds are placed below the surface to protect the bed from scouring.

The plan on which the last, the circular tank, has been constructed is worthy of note; it is built in a series of rings or off-sets, increasing in diameter from the bottom upwards; the perpendicular distance between each off-set is about 5 feet, and the off-set itself about 1 foot in width. There are two places where these off-sets have been omitted to facilitate the drawing of water; over each a pulley can be arranged for hoisting the bucket. The advantage of these off-sets is the facility with which it enabled men in the first instance to construct the tank and afterwards to effect repairs.

All the tanks are furnished with flights of small steps constructed on the sides wherever necessary or convenient.

Perhaps it may prove useful to state the manner in which these tanks have been plastered. Whenever any uncertainty existed as to the nature of the ground, it was roughly paved, leaving joints of about 1 inch width; this lessens the chance of crevices occurring between the stones which might sometimes occur if they were set close. On this, concrete composed of equal parts of lime and gravel was well rammed. The thickness of concrete depends upon the height from which the water had to fall; about 1 foot in thickness of concrete for 10 feet fall is sufficient. Over this, 3 inches rough casting (composed of 1 part chunam, 1 part sand, and 4 lbs. hemp, per 100 square feet, well mixed) is laid in layers of about 1 inch at a time; and when the rammer emits a clear hard sound, the final coat of plaster is added, composed of 10 parts chunam and 1 part sand.

The lime at Aden is obtained from coral, and is of good quality. Care should be taken to prevent heavy rain from falling on the plaster until it has properly set, and it should also be shaded from the sun in the hot weather.

The total contents of the Government tanks, including upper lakes formed by bunds, are about 11,000,000 gallons. A moderate fall of rain, say about 3 inches in 3 hours, would fill the whole system, and in a few times would repay Government well for all outlay incurred: but unfortunately we have had so little rain in Aden since the tanks have been completed, that it is not fair to draw conclusions. Every shower of rain saves Government so many rupees, and gives the troops and others at Aden the blessings of good sweet water. Hitherto the water collected, owing to the scarcity of rain, has not proved anything like sufficient.

S. S. J.

No. CXII.

ROADS IN COORG.

Abridged from a Report by MAJOR R. H. SANKEY, R.E., *Assistant to the Chief Engineer, Mysore.*

IN 1862 a small platform bridge 9 feet wide by 4 feet high, placed in one of the numerous short embankments on the Mercara-Veerajendrapett road in Coorg was carried away by a flood, and the Engineer, Mr. Stoddard, submitted an estimate amounting to Rs. 2,110, for reconstructing the work, increasing the bridge to a span of 12 feet, and raising the embankment throughout—making, in fact, apparently all reasonable provision for meeting the requirements of the highest probable flood.

But the floods of 1863, proved much more serious than had been anticipated, and a second design had to be framed, for a bridge of double the capacity. Last year's floods coming down with still greater power, and further the labor rate having sensibly increased, a third revision was found essential, bringing the estimate up to Rs. 14,960, or seven times the amount originally contemplated.

Viewing the whole circumstances of this case, and others bearing a close analogy to it, the Chief Engineer considered a strict enquiry on the spot essential, and with this object I proceeded to Coorg on the 19th ultimo. Having now carefully inspected the works in question, I am clearly of opinion that the Executive Engineer has acted with all reasonable foresight, in framing his successive estimates, with the data of previous floods before him, but that from the daily changes now being wrought, in the physical condition of Coorg, these data cannot be accepted as guides to the future.

In the former condition of the country, when dense rolling forest covered all but the mountain tops and the rice lands in the deep intervening valleys, the rain-fall was in part sucked up by the redundant vegetation, in part absorbed into the earth—being stopped from flowing off by thickly interlacing roots—in part evaporated from countless leaves and stems, and only probably a comparatively small portion, enabled to flow off at once into the various streams. It appears to me however, that in consequence of the great areas of forest land, now laid bare yearly by the planter, the rain-fall is discharged much more rapidly down the mountain slopes than was formerly the case, among other results giving rise to floods of yearly increasing magnitude. That such must necessarily be the result of extensive clearings, would I should think be at once admitted. I shall give hereafter certain proofs that at least the argument does not rest on theory—meanwhile the mere statement of the fact, in reference to a country with the known heavy[*] rain-fall of Coorg, must give rise to vague apprehensions for the future.

The consideration of the general question, as to the effects of clearings in other tracts as well as Coorg, on the bridges, anicuts, and other river works, down to the sea, though naturally following, is much beyond my powers and present object, I trust however I may be excused for deeming it of sufficient importance, even in the limited sense of its direct effect on Coorg works, to warrant my converting what was originally intended as a simple professional report on two or three individual works, into one of a more general nature, relating to the present position of the Department and the work before it, under the peculiar circumstances above described.

The present time also appears for other reasons, suitable to such a consideration of our position. It was not till three years after the British had possessed themselves of the country, that the impossibility of moving a force into South Coorg—to subdue the rebellion which had there sprung up (1837)—demonstrated the absolute necessity of constructing some kind of Military road, and the Sumpagee ghaut was made by Lieutenant Fast of the Engineers. The Anachowkoor road and Periambady ghaut were finished some twelve years later, also as a military necessity—the old line to Cannanore, through Wynaad and by the Perriah pass, proving altogether impracticable. The connecting road between Mercara and Veerajendrapett, with a similar military object, was made shortly afterwards. At this moment these three military roads, remain practically the* only ones devoted to wheeled vehicles in the country, and it will be seen from what follows that even these—masterpieces of engineering as they were, when first driven through almost impenetrable forests—are in many places quite unsuited to the requirements of the cart traffic which has now set in upon them, and which with the altered physical conditions above alluded to, coupled with other causes, threatens to render them entirely unserviceable, unless energetic measures be adopted for their preservation, and reconstruction in places. When in addition to this it is borne in mind, that hardly a portion of Coorg, with the exception of Nalknad, remains unoccupied by planters, there can be no reasonable doubt that the whole country will be the scene of European enterprise, in a very short period—Coorg in fact forming with Monzerabad on the north, and Wynaad on the south, a vast connected colony. It therefore appears to me perfectly clear, that even were the main roads above alluded to, in thorough working order, they would only in a very partial degree, meet the first wants of the country, and that an imperative necessity exists for devising some practical means of giving a more extended series of communication.

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[*] Rain-fall at Mercara—1863-64, 135 inches; 1864-65, 143 inches. It is believed to be much heavier at Periambady ghaut.

To facilitate reference I have constructed the accompanying Map, from such information as I could procure. The Trigonometrical Survey shows only the old native tracks, and it may be doubted whether the topographical features are very correctly indicated. We have no actual surveys of the Ghaut Roads; they are however here I think sufficiently well laid down, to answer my present object. The heights above sea level have been determined from means, struck on the observations of the Rev. Mr. Richter, Mr. Stoddard, and myself; being however taken with the Aneroid, they can only be accepted as approximations.

With reference to the condition of the Ghaut roads, in regard to gradient and soil, I would invite attention to the longitudinal sections herewith given. Though the slopes have been roughly determined, without the use of the instrument, they will be found sufficiently accurate for all practical purposes, and show at a glance the weak points claiming early attention.

First in the list is the Mercara-Fraserpett road, 19 miles. This is probably the most defectively traced line in the country, for it will be noted that although there is only about 1,000 feet difference in level between the termini (giving an average fall of 1 in 100), there are two places between the 3rd and 5th miles, with gradients of 1 in 9, and 1 in 10, and many others with 1 in 15 and 16. The present condition of the steepest portion is most distressing. The longitudinal slopes being as great or greater than the side slopes, the water tears down the centre of the road, ripping up everything but large boulders, and the surface repairs, made from the trifling maintenance allowance, Rs. 150 per mile, are altogether useless.

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* Carts, it is true, have passed over the new Mercara-Codlipett road, but the work is far from complete.

The Coorg hills being composed of metamorphic rock in which felspar is largely present, all near the surface is decayed, and there is very little really good gravel to be procured. Good gravel indeed appears only to be met with in laterite formations, at a few points along the Tulla Cauvery road; also between Veerajendrapett and Periambady, and again on the Bittengall road with perhaps a few other isolated spots. Metal is procurable either by blasting, or from the embedded boulders met with in excavating the scarps. While therefore presenting great facilities for first formation, it is evident that very serious evils result from the geological structure of Coorg, in regard to two of the main requisites of ghaut roads. The first is, that the foundation of the road must be soft and yielding, and that there is no proper top dressing present, for such metalling as may be laid down; the second, that the side scarps and other portions readily yield, and fall away with the slightest run of water on the surface—there in fact being no coherence in the soil.

To my mind therefore, a new trace of at least all portions, with gradients above 1 in 18 is a first necessity. The portion between Mercara and Sonticoopa being the worst, I would urge an entirely new line being made. Without a more careful examination of the country, trial traces, levels, &c., it would of course be quite impossible to say what actual line should be adopted, I am however satisfied that on all professional grounds, as also from the stringent orders issued by the Government of India, in regard to gradients of ghaut roads, (the maximum having been expressly limited to 1 in 22,) no other conclusion can be arrived at, than a thorough reconstruction, for the upper portion of this road. Between Sonticoopa and Fraserpett, it will also be observed, that there are in places, very objectionable gradients. The adoption of zig-zags, or a slightly more

circuitous route in one or two places, amounting in the whole, to (say) a reconstruction of 3 miles, should I imagine, suffice. I would also observe that in addition to other objectionable features, high jungle lines the road closely for several miles, chiefly in its lower portions, and if not removed at once by planters (the undergrowth being left to preserve the surface) should be cut down to 15 yards on either side of the road. Halting places for carts and cattle off the road should be provided, and stringent regulations enforced regarding their use.

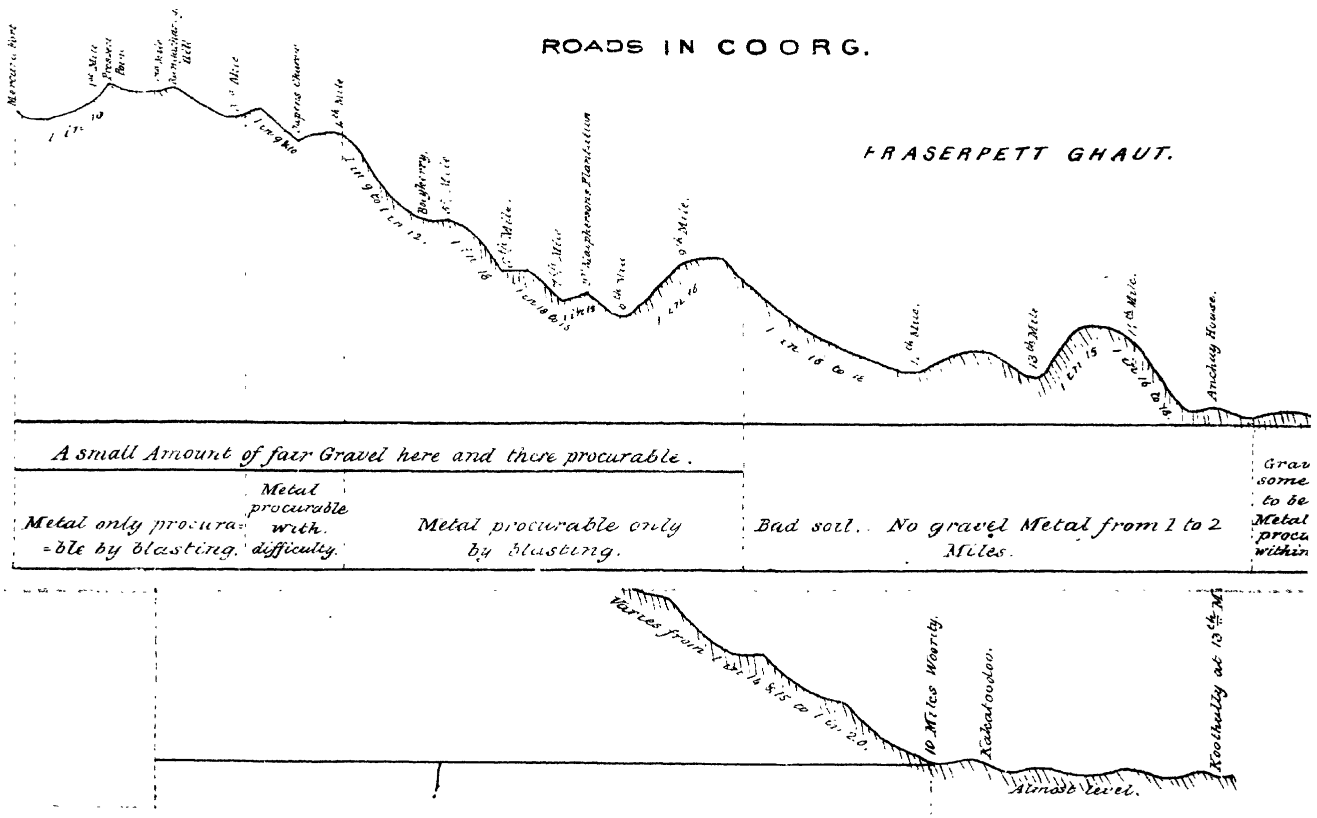
The Sumpagee Ghaut, 19¼ miles in length, and leading direct to Mangalore, is the next line claiming attention. This great work, the first of the 14 or 15 roads now carried through the Western ghauts, is undoubtedly the best in Coorg, and so far as I can judge only requires trifling rectification between the 9th and 10th miles. At the upper portion of the mile the slope is 1 in 12, and for a short distance approaching a bridge over a ravine, at the 10th mile, as much as 1 in 6 or 7. There is a deep narrow gorge at this point, which no doubt rendered the selection of a better line almost impossible, with the features of the neighbouring slopes, shrouded in dense forest. Even now with nearly all laid bare, it is no easy matter to choose another, and although from my own personal examination, I am satisfied the line can be carried by a zig-zag in another direction, very careful alignment will be required. At a rough estimation, I should say 2½ miles of new ghaut would have to be made. It will be observed that from about the 2½ to the 4th mile, there is a counter gradient; this however was essential, in order to get over the saddle on one of the lower spurs of the range, running off towards Tulla Cauvery. The ghaut is nearly metalled throughout, indeed I might say paved, in its lower portion. The metal is staring and gritty, and I should fear would in great measure be swept away, if means cannot be found before next May, for protecting it with gravel, and a well formed up roadway.

Several slips have occurred in this line, the most serious one being below the 10th mile stone. This resulted in a great measure from the clearings both above and below the roadway, and though a passable road has been constructed across the breach, some permanent arrangement must be made for diverting the upper drainage, and leading it off to the stream below. The side cuttings in the first mile near Mercara are extremely heavy, one double escarpment being about 90 feet high, and the drop on the lower side of the road precipitous to a degree. Some thick growth should be encouraged here to obviate all possibility of a slip which, if it occurred, would be fraught with the most serious consequences. Halting places for carts are also required on this ghaut.

The total fall in the first 15 miles of this Ghaut is about 2,900 feet, which gives 1 in 37 for the whole line, but it will be observed that the influence of the counterslope has prevented this being worked out. From the foot of the ghaut to the town of Sumpagee, 4½ miles, the fall is only about 55 feet.

The next Ghaut in order of succession, is the first 2½ miles of the road leading out of Mercara, towards Veerajendrapett. At the end of the 1st mile and after passing the second, the gradients are 1 in 9, and in nearly all other portions excessively severe, so much so indeed that I would beg to recommend entire reconstruction. The side cuttings in the upper portion are also extremely heavy, and as this part perhaps afford the most marked example of the effects of clearings above ghaut roads, I herewith attach a rough sketch which I made of the first mile of this ghaut, as seen from the Sumpagee. Here it will be observed on the central hill, that the planter, to prevent the soil being washed away from his trees, ran the horizontal drains *a*, *a*, *a*, *a*, *a*, but these becoming surcharged, burst at different points, forming the perpendicular channels *b*, *b*, *b*, *b*, at the end of each of which, most formidable breaches have occurred. These four slips in this short space are each I should say at least 100 feet high. On their occurrence it took several days with the utmost exertions to clear the road, and in two cases the breaches carried away the roadway itself, occasioning the most formidable chasms on the lower side. My own opinion is that unless some thick growth be at once encouraged on this hill, the next monsoon will see these breaches greatly extended. In fact, there appears every likelihood of the original form of the hill being altered, and the work, in preserving the road, becoming endless.

As a distinct proof that to upper clearings, are to be attributed nearly all the serious slips which have taken place, I would point to the present condition of the cutting mentioned above, as also to the weathered, and apparently perfectly safe condition of many other similar scarps, where the upper surface of the hill has not been disturbed. Every one passing through Coorg, has been struck with the gigantic trenches, carried through deep valleys, and along the tops of the highest hills, serving as ancient boundary marks (Kodungas). Some of these are nearly 40 feet from


ROADS IN COORG.

FRASERPETT GHAUT.

PUBLIC WORKS IN COORG.

PLATE XXXIII.

summit to bottom of ditch, and often taken along hill sides with an angle of 80° to the horizon; yet though hundreds of years old, the edges of most of them are as sharp as possible, in spite of the natural incoherence of the soil. This simply results from the surface not having been ever disturbed.

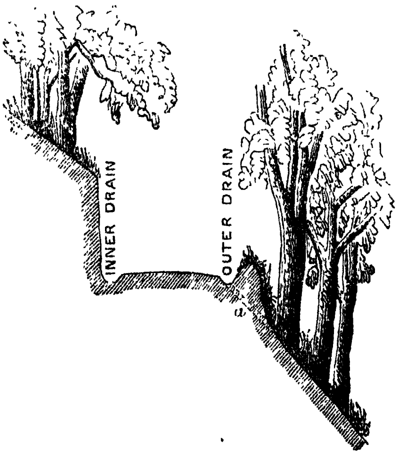
The total fall in this ghaut is about 550 feet in 2½ miles, giving 1 in 24 over all; there are however two short counterslopes, which have thrown out the remaining gradients.

The fourth and last of what may more especially be termed, Ghaut roads in Coorg, is that at Periambady—10 miles in length—leading down towards Cannanore. It will be observed from the section, that for the first 2¼ miles the slope is sufficiently gentle, but for the three-quarters of a mile just above the Wotacolly bridge, there is a distressing gradient of 1 in 10 and 12. The road after this is easy and level in places to beyond the 4th mile, from which it drops down to Woority with generally far too steep a gradient.

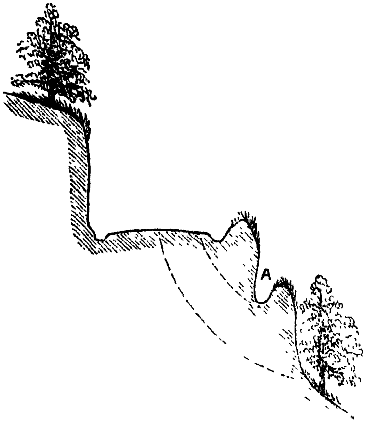
I have very little doubt, that by carrying the line along the southern slopes of the hill at Wotacolly, 1½ or at most 2 miles of new ghaut would overcome the objectionable gradient above the bridge. Now that the hill sides have been laid bare and planted, it is easy to see that an alternative line lies in this direction; but when Captain Francis laid out the ghaut, so dense was the undergrowth and vast the forest overhead, that no neighbouring feature of the country could be seen from below. It was only in fact by lighting fires along the trace and standing on a bare topped mountain, commanding the ghaut, that the direction with reference to the adjoining ground could be ascertained. The alteration of the lower portion of the ghaut is a different matter. Though undoubtedy desirable, it is not easy to see how it could be effected. The point on the section, named the Jemadar's rock, is, so far as I can judge, the top of a precipice of sheet rock, across the face of which it having been found impossible to work, it was allowed to rule the gradient down to Woority. Once this point was accepted, I conclude there was nothing for it but to lay out the ghaut as it now exists; the hill side, along which it is carried, being at far too steep a slope to allow of length being gained by a zig-zag.

I found the upper portion of the ghaut, where the gradients are easy, all in fair enough trafficable condition and being metalled, but the evils of too steep a gradient were at once apparent lower down. Previous to the ghaut roads being taken over by this Department in 1862, the Madras Government had spent some Rs. 60,000 in metalling this line, but chiefly from steepness of gradient, the metal (unfortunately very thinly laid on, and placed on an imperfectly barrelled road) was almost wholly swept away, and only traces of it can here and there be observed. In the first rough shaping of the ghaut, many boulders had been left, and others of a smaller size were probably thrown in from time to time, to fill up the deep channels cut by the water tearing down the ghaut; its dreadful condition can therefore hardly be exaggerated.

In speaking of the Veerajendrapett Ghaut, I have shown the effects of clearings above hill side scarps. The portion of this (the Periambady) Ghaut already cleared, showed in many places on the other hand, the evils of clearing on the lower side of the road, where the side slopes are great. When forming the original roadway, Captain Francis adopted a simple barrelled surface as in ordinary roads, thus throwing half the drainage over the hill sides, by small cuts (*a*) from the outer drain at every 30 or 40 feet, as roughly shown in the side section. The plan answered admirably in the former uncleared state of the hill sides, fewer cross drains being found necessary, and the thick vegetation on the outer slopes preventing the chance of the soil being washed away and breaches resulting. The moment however the slopes were cleared of jungle, the whole condition of matters changed. The planter to prevent the soil being washed from the lower slopes, very naturally cut the longitudinal drain A, in the next section. This unfortunately operating in undermining the bank, frequent breaches of the nature shown by the dotted lines, have been produced.



The Executive Engineer, to help out matters as much as he could, has been endeavouring to dispense altogether with the outer drain, by raising the outer side of the road, and throwing the whole drainage into the inner drain, which having thus double its previous work to do, required to be eased by new cross drains at closer intervals; 52 extra cross drains are therefore now in the course of construction, but the attendant difficulties are of a very serious character. To obtain an outfall for these drains, which shall be free from the chances of occasioning frequent breaches, seems very nearly an impossibility where the hill side is laid bare, and unless very thick planting can be maintained down the side of the channels, I do not see how the matter can be managed.



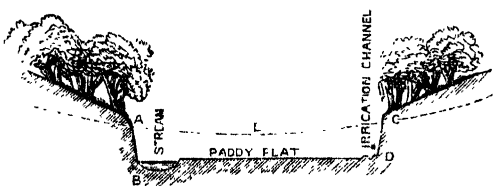
For all existing uncleared ground along ghaut roads, I would venture strongly to urge the necessity, of preserving a belt of low jungle, both on the upper and lower slopes, of from 40 to 50 yards wide. Indeed to ordinary observers, it would appear to be quite as little in the interests of the planter, as of Government, to cultivate slopes which are so steep that the upper mould is easily washed off, and where, as is not unfrequently the case, such slips occur that plants and all are washed into the valley below. Hill sides are now planted at angles of 45°, 50°, and even 60° to the horizon, when it would hardly appear possible to preserve for any length of time, the surface soil on slopes of more that 20°. I am informed that it is the practice on steep slopes, to plant the coffee trees closer together, but in any case the ground between must be kept clean and free from weeds, so that the evil is only very slightly mitigated.

There are now about 7 miles of the Periambady ghaut to which my remarks especially refer, as the forest is as yet standing, and it is with regard to this I should be glad to see some decision arrived at. The slopes are extremely steep for the last 6 miles of the ghaut, and all along may be observed the noblest spars of Poon (*Calophyllum bracteatum*), Anjely (*Artocarpus hersuta*), Chittagong wood (*Cickrassia tabularis*), Honay (*Pterocarpus marsupea*), Sumpengi (*Michelia champeca*), Red Cedar (*Cedrela toona*), and many other timbers, whose value on the coast is I understand rising daily, and which therefore, it would appear most desirable to conserve.

Having described at more or less length, the ghaut portions of the through main lines of communication, I would beg to draw attention to the two connecting links, viz. the road from the foot of the Veerajendrapett ghaut to Periambady—21½ miles—and that from Periambady through Attoor and Tittamutty, leading towards Mysore—39½ miles to the frontier.

As both these lines partake very much of the same characteristics, I may at once state, that they are a perpetual series of rises and falls, being carried across low spurs of hills, with intervening paddy flats. The gradients are frequently very bad indeed, but being for the most part over short pieces, I would not suggest any rectification at present, draught cattle being able to make the needful exertion when the strain is not too continuous; metal however should undoubtedly be employed, and the form of the road preserved. Felling of high jungle on either side is also much needed in many places.

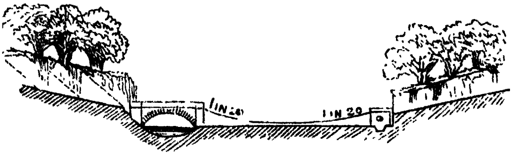
The point however chiefly requiring attention in both roads, is how to deal with the embankments crossing paddy flats; these having suffered most severely from floods, during the last three years—these floods, as I have at the commencement stated, being I believe progressive, in proportion to the extent of land cleared for planting, and liable as has already been the case, to stop all communication, by blowing up the bridges, &c. These flats or cultivated Coorg valleys, present quite a peculiar section, the result no doubt of the incoherent nature of the soil before alluded to. Instead of gently sloping off into the valleys, the hills terminate always in abrupt banks (AB and CD in the above section,) which vary from 20 to 40 and 50 feet high—the stream shown at the left corner, having probably wandered from side to side, (*i. e.*, from B to D,) much in the manner of the Ganges, and other rivers of Upper India, within the limits of their "Khadir." An irrigation channel taken off high up, runs usually along the other side (D), and the stream when surcharged, inundates a large portion, if not the whole intervening space. These paddy flats vary in width from 100 to 500 yards as a rule. Some however in South Coorg much exceed this, presenting magnificent sheets of cultivation girt by densely wooded hills.



In carrying a road across such places, (they are met at distances varying from half to two miles apart,) the plan adopted was to throw an arch over the stream at B, also a tunnel for the irrigation channel at D, the roadway being formed in embankment, somewhat as indicated by the dotted line in the above section. In the middle of this embankment at E, was also constructed a small bridge for the discharge of surplus inundation water.

These arrangements answered sufficiently well, so long as the floods remained within their original bounds—now, however, that the tendency to increase yearly has shown itself in several cases, the irrigation drain at D, and in more cases, the small bridge at E, have blown up. Five embankments crossing paddy flats between Mercara and Veerajendrapett, have thus suffered during the past two years. In the early part of this monsoon, the Kokeloor embankment, close to Veerajendrapett, was for the first time since its construction, (supposed to be 15 years ago,) over-topped, the flood standing 4 feet above the small central bridge, which it fairly blew up, transporting the whole of the materials to a distance of some 50 or 60 feet. The bridge over the stream at B, has always been saved by the destruction of the smaller one at E, the inundation water thus venting itself—but it is perfectly clear that if we go on increasing the embankment to what we consider a safe height, and rebuilding the central bridges at E, considerable risk will be incurred of throwing too great a portion of the flood through B, and destroying thus the main works. Most of the latter are single span bridges of 40 to 55 feet, and were very costly.

In dealing with what, as I judge, has now become a gradually accelerating force, the first necessity is to provide for the safety of the bridges at B. I would therefore instead of raising the embankment and rebuilding the bridge at E, cut down the former and omit the latter, making the whole assume the section shown, which allows the inundation after a few feet rise to flow over the centre of the embankment and thus vent itself innocuously.



There are only two essentials in dealing thus with the matter, viz., first, that the gradient of the approaches shown should be a maximum; and secondly, that the central point of the embankment should be kept as low as possible consistent with this. I have every reason to believe that no flood would thus interrupt the communications more than three days at the farthest, and a few trifling repairs to earthwork would suffice after its retirement.

Having now reviewed the state of the main lines, I will briefly refer to those under construction or proposed.

The road now under construction between Mercara-Somwarpett—and Codlipett—44½ miles—was commenced some three years ago, and during last year had made such advance as to admit of carts going over it. Of course however the work is far from complete. The original idea in thus connecting Munzerabad and Coorg, was to run the line to Sonticoopath, but it was afterwards altered to Mercara, as holding out greater advantages. The line having been laid out, under stringent regulations in regard to gradient, and the trace receiving great attention, the result is a road with uniformly the best gradients in this Province. With one or two very trifling exceptions, I think the maximum gradient throughout the line as far as Somwarpett, may be pronounced to be 1 in 18; 1 in 20 is common on the ghaut portions. In ascending the hill beyond Somwarpett, I fear the gradient is 1 in 16, but after that to Codlipett, 1 in 19 and 20 is the maximum—the line in most places being very easy and often nearly level. Most of the roadway is 18 feet wide. There are places 16, others 14, and even only 12 feet wide: but these form a small proportion, and I should think that in three months the full width will be attained from first to last. The work is progressing with very creditable activity.

For the Choranhully, a single timber trussed span of 50 feet is proposed; for the Mahdapoor two similar spans, and for the Huttyhulla three spans of 50 feet. All of these streams run eastward, forming after their junction the Haringhy river, which joins the Cauvery a little above Ramasammy Cunavi. The Choranhully is narrow, and having a rapid longitudinal fall, comes down with great force when in flood—a causeway is therefore inapplicable, as also the maintenance of communication by means of a ferry. I see therefore no other course than to construct the bridge as proposed. The Mahdapoor has already had a rough stone causeway thrown over it, which has perfectly withstood the last two monsoons. As it answers every purpose of cart traffic for nine months in the year; and as further, the communication during the remaining three, is now maintained by basket boats, (two wretchedly small affairs which should be replaced by a proper ferry boat,) I do not see any very urgent necessity for bridging the stream. The same remarks apply to the Huttyhully, across which the Executive Engineer is about to construct a causeway, similar to that at Mahdapoor.

The next work of communication now under execution by this Department, is the trace of the proposed line from Veerajendrapett, viâ Ammuty and Seedapoor to Fraserpett—in all 28 miles. Of course, like all Coorg roads, the trace is up and down hill, and crosses paddy flats at every one or two miles. I found however the gradients all very fair, the only real difficulty being in, and immediately leading out of, the town of Veerajendrapett itself. Within the limits of the town, the main streets of which have gradients of 1 in 10, it has been found necessary to bring in the new line from the Mercara road, and then take it by a zig-zag up the face of a hill to the east and over a saddle.

In addition to the roads designed, and carried out from Imperial funds, others are now being constructed by planters from their own private means. Though not having personally inspected these, and thus unable to offer any accurate information regarding them, I think it only right to place on record, however imperfectly, the facts connected with this new and encouraging element of advance, and have therefore shown roughly on the map, the direction of two of the most important of the lines in question.

Having now shown generally the condition of the existing work in Coorg and what rectifications are urgently called for, I now turn to a matter of very nearly equal importance, namely the communications needed to keep pace with the rapid spread of European enterprise in nearly every part of the Province.

The Bagamungalum-Sooleah road, has already been sufficiently alluded to. That proposed from Veerajendrapett, viâ Nalknad to Bagamungalum, would if added, open up probably the finest forest land in the country, and with the Sooleah road, supply a through independent Western communication, valuable alike for commercial and administrative purposes.

The next line, namely, that proposed from Veerajendrapett to Wynaad, would I presume lead, as I have roughly shown on the map, through the town of Kuggutnad, and I would recommend that advantage be taken of this new proposed line to Kuggutnad, to open an entirely new road over.

this portion, tending more to the east where the lie of the ground appears favorable.

From all that I can gather, it would appear that Kuggutnad in addition to this direct connection with Veerajendrapett, would equally need a line leading eastward towards Mysore, joining the Anchowkoor road at some such point as Tittamutty.

The Seedapoor-Fraserpett, and Seedapoor-Periapatam proposed lines, have already been sufficiently adverted to above; it only therefore remains to note that from Fraserpett to Somwarpett, on the Mercara-Codlipett road. The necessity for this road has long been urged, I have therefore roughly shown on the map the direction it would take.

The total length of these several district roads may be assumed roughly at 156 miles. To attempt to open these, as fully bridged cart roads, even without metalling, would certainly not cost less than Rs. 3,500 per mile, or a total of Rs. 5,46,000, an amount that with the more urgent calls for rectifying the defective ghaut roads and other engagements, renders it impracticable to aim at this high standard. The main object, which is to execute these works at once, would moreover be defeated. After giving every consideration to the subject, I venture to believe that the real wants of Coorg, would be met by a system of roads suitable to pack-bullock traffic, but traced with such care and deliberation, that they may be individually worked out to cart roads, the moment funds can be spared. Such roads, three yards wide everywhere, with log bridges, maximum gradients on all straight portions of 1 in 19, and at all bends, of 1 in 22, and having causeways over the largest streams, could, I am satisfied be opened for Rs. 600 per mile, allowing the whole network to be executed for Rs. 93,000—or, if the work is to be done in four years—requiring an assignment of say Rs. 25,000 per annum, in each successive Budget.

Very little more than the actual tracing need in practice fall on this Department, as I have no doubt the planters would find it for their own interest, to take certain lengths of line in their neighbourhood upon contract, and work them out by estate coolies. Nay more, I should think, they would be perfectly willing to do the work at once, if guaranteed repayment by Government within the specified four years. However, this is a question they can better answer for themselves. It is clear that for them to do the work, would disturb the labor market less than if *we* did it, and being all of a simple nature and precisely similar to work done every day on the estate, I think it would be found to answer. The Executive Engineer should of course alone lay down the trace and specification for the work, naming the terms, and exacting the strictest adherence to all, on penalty of non-payment. The interests of all parties it seems to me, would thus be met.

As showing the importance of such a system of roads, I would beg to make a brief quotation, from an able and suggestive article on "the Southern Ghauts," in No. LXXVI. of the Calcutta Review, for 1863. The reviewer observes: "We have stated above that in 1853, the Madras Commission on Public Works found that the roads of Canara were returning to Government a nett profit of 20 per cent. from the two sources of land and salt revenue; we shall now take the ten years from 1851 to 1860, and show what has been the progress from about the last year, on which the Commission forwarded its report, to the last at our command. Omitting all fractions below a quarter of a lakh, we find that the import trade rose within the above period from 4½ lakhs to 25½ lakhs; the value of exports rose from 30½ to 102¼ lakhs; thus the whole trade increased from 34¾ lakhs to 127¾ lakhs. In the same period, the salt revenue rose from £14,000 to £31,000; that is to say, was more than doubled"—and more in the same strain. Since this remarkable statement was made, the spring which has been given to enterprise in Coorg, has mainly taken place, and if we could only analyse the returns, the direct gain by Madras would, I am satisfied, be shown to be equal to the whole demand I have ventured to claim for the Public Works in Coorg.

Before closing this Report it is necessary I should remark that in the matter of labor there are great difficulties in this province. During the monsoon, when the ghaut roads require close daily attention, hardly a man is to be had. Mysore coolies who all belong to the agricultural class, have by that time mostly vanished, or find easier and more congenial work on the coffee estates, where each man in addition to his 4 annas per diem, can turn a few annas by the sale of firewood, &c. Mapillay coolies, who require Rs. 10 per mensem, will only work in the low country at the foot of the ghauts. Madras men will again only work on the Periambady-Anchowkoor road, salt fish being easily procured there, &c.

The extreme unhealthiness of portions of the ghauts also frightens labor away from our works. Not a single cooly can at times be induced to go down the Sumpagee ghaut in the monsoon. Many years ago

Captain (Major-General) Frederick Cotton, proposed to establish single cooly huts at every mile, but this as well as other similar attempts in the same direction, have failed signally. Mr. Stoddard has however now, with the sanction of the Chief Engineer, commenced the construction of permanent cooly lines at convenient distances and in comparatively healthy localities. Nine of these now in hand are shown on the map. A small hut attached answers for the road overseer. This system certainly holds out fair hopes of success, but still labor must remain precarious and expensive, coming as it does from a distance.

P.S.—Since writing the above, I have incidentally learned that the same hurrying down of floods adverted to above, accompanied by breached roads and blown up bridges, followed the first clearings in Ceylon, but that some kind of equilibruim has been of late years established by a sensible falling off of the yearly quantity of rain—to the extent of one-third the previous amount. My informant, however, could neither afford me accurate information nor refer me to any printed record. Should this enquiry prove to be well founded, a serious question will follow as to the effects of clearings on the summer water of the Cauvery and the irrigation dependent thereon.

R. H. S.

BANGALORE,
11*th November*, 1865.

No. CXIII.

ON THE THEORY OF ARCHES.

BY ALEXANDER H. MACNAIR, ESQ., *Resident Engineer, E. I. Railway.*

THIS paper is an attempt to construct a theory which shall be of practical value, and to demonstrate the same without the aid of the higher mathematics. In order to present it in a form sufficiently complete to be intelligible, within the limited space which can be afforded, much of the reasoning is merely indicated, and no effort has been made to distinguish what is novel from that which is only a reproduction of the works of others.

MOTION AS OPPOSED TO STABILITY.—The failure of an arch or other building implies motion among its parts, for it cannot be said to have failed till this has occurred.

A stone resting on the plane AB, Fig. 1, and still remaining in contact with it, may be moved in either of the following ways:—1st, It may slide towards A or B. This is called motion of translation. Or 2nd, It may turn on the edge A or B. This is called motion of rotation. Or 3rd, It may by increased pressure approach nearer to AB, or *vice versâ*. If the pressure is insufficient to crush the stone, it will tend to produce rest or stability, but otherwise motion or failure. And no other kind of motion can take place in the stone still remaining in contact with AB, which is not a combination of some or all of the above.

Now, if the pressure be unequal, the stone may be crushed at one end of AB and not at the other, causing a motion of rotation; the centre of which is a point between A and B. And this is the only case which occurs in practice in an arch. Therefore the stability of arches is endangered *only by unequal pressure.*

[Throughout this paper the points of support of the arch are regarded as immoveable.]

THE LINE OF PRESSURE.—Let Fig. 1, be the vertical section of a stone of equal thickness, passing through G its centre of gravity, and intersecting its horizontal plane of support in the line AB. It is evident that the line of direction (of gravity) GC bisects AB, that the pressure on AB is equal everywhere, and that the total pressures on each side of GC are equal to each other.

In Fig. 2, let the *shape* of the stone be altered, its weight and other conditions remaining the same as before. Then the total pressures on each side of GC, are still the same, but the pressure is greater at A than at C, and at C than at B, because C is nearer to A than to B.

If now, as in Fig. 3, we make CD = CA, and cut off that portion of the stone supported between D and B, and support it on the stone itself, so that the centre of gravity remains on the same vertical line, the area of support is thereby diminished, at the same time that the pressure at A is reduced, because the pressure on AD is now made equal everywhere.

In Fig. 4, let GC be the line of direction (of gravity) of an arch stone supported on AB. The pressure is greatest at A.

In these examples GC is the Line of Pressure.

But the arch-stone may be acted upon by another force besides its weight, as for instance, an external force in the direction DE, *Fig. V.* Then the centre of pressure is at E, where this intersects the direction of gravity. And the Line of Pressure is in the direction of the resultant of of the two forces, intersecting AB in some point F; and the pressure is greatest at A or B, according to their proximity to F, and equal everywhere only if F bisect AB.

To put these results into the form of a definition. In the vertical section of an arch, at right angles to its axis, there is a line of contact between every two adjacent voussoirs, and a point in that line which divides equally the total pressure exerted by these voussoirs against each other. The line which passes through all these points is the LINE OF PRESSURE.

[I have pursued this investigation on the hypothesis that the material *is compressed*, and that the resistance developed, (which is the pressure,) is

THEORY OF ARCHES.

Fig. 1.

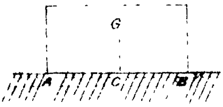


Fig. 2.

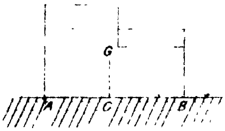


Fig. 3.

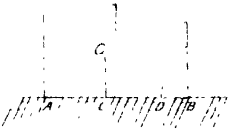


Fig. 4.

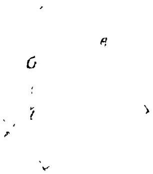


Fig. 5.

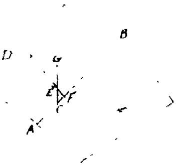


Fig. 6.

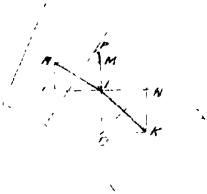
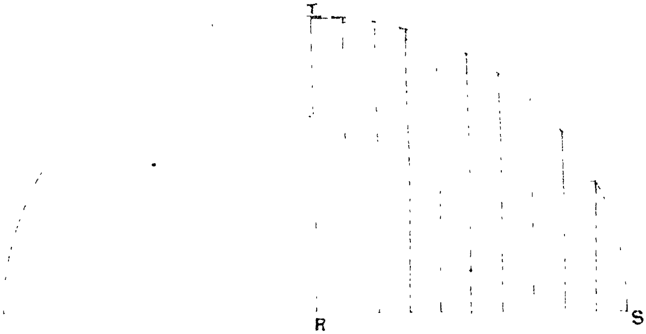


Fig. 7.



correctly measured by the amount of compression. The following is the result in algebraic symbols—

$a = $ AF.
$b = $ FB.
$p = $ pressure at F (mean)
$x = $ ditto A (greatest)
$y = $ ditto B (least)

$$\frac{}{a^2 + b^2}$$

Let $y = 0$
then $x = p\sqrt{2}$
and $b = a\ (2{\cdot}4142)$

so that if AF is not more than two-fifths of FB, there will be no pressure, but an open joint, at B.]

Before proceeding to the next head, it is necessary to define the sense in which certain terms are used in this paper.

Moving Load requires no explanation.

Permanent Load is that which is necessary to render the arch useful. At the crown of the arch there are always the *arch-stone* and the *permanent load* on it, and occasionally the *moving load* also. The permanent load is uniformly distributed over the span of the arch.

Backing is that which remains on the arch-ring when the moving and permanent loads are both taken away. It is more or less essential to the stability of the arch, and in reference to its weight, must always be taken into consideration along with the arch-ring.

Arch-ring requires no explanation.

Structure includes all of the above except the first.

CAUSES WHICH DETERMINE THE LINE OF PRESSURE.—1st. *Weight of Structure.*—In illustration of this I shall consider one case, viz., that in which the structure is designed so that the Line Pressure shall bisect all the lines of contact. And for the present let the Permanent load $= 0$.

In Fig. 6, let HI, IK, be straight lines joining the centres of gravity of three arch stones, of such dimensions that the horizontal distance of I from H is equal to that of K from I. It is required to determine the conditions of stability of the middle stone, so that the Line of Pressure may pass through the points H, I, and K.

The diagram itself will show how this is accomplished. The point I is kept at rest by the equal and opposite horizontal forces, LI and NI, and the vertical forces PM + MI, which are together equal to the opposite force OI. Now MI is the whole weight supported at H; and because this is not sufficient at I we have to add PM, which must therefore be the weight of the arch stone at I, and the backing directly above it. It remains to calculate PM.

In Fig. 7, we pass on to the consideration of blocks of masonry having their centres of gravity in vertical lines which are at equal distances from each other. These blocks make up the structure, which in this case consists of the arch and backing alone. And by comparing Figs. 6 and 7, it is evident that to calculate PM for any one of the vertical lines, we must find the length of the portion cut off from that line, and deduct from it the length of the portion cut off from the line before it (towards the centre). The remainder is PM. This can be done in various ways.

Tables are given below for Radius divided into 10 equal parts. Their application will be readily understood, bearing in mind that PM, at the crown is *half* the weight of the vertical block, and in every other position it is the *whole* weight. The first three Tables are general. No. IV. requires to be made out for each arch, after the Radius of the Line of Pressure and depth of the key-stone are known. It is subdivided to show the difference in backing between two arches otherwise alike, caused by a difference in the depth of the arch stones, which is worthy of notice. Fig. 8, shows two semi-arches drawn according to this Table.

RADIUS DIVIDED INTO 10 EQUAL PARTS.

No. of division from centre.	RADIUS = UNITY.			RADIUS = 10 FEET.	
	Table I.	Table II.	Table III.	Table IV.	
	Versed sines.	Differences of versed sines or lengths cut off in Fig. 7.	Differences of last Table, or value of P M.	Height of block, when key-stone = 1 foot.	Height of block when key-stone = 2 feet.
0	·0000	·0050	·0050	1·00	2·00
1	·0050	·0152	·0102	1·02	2·04
2	·0202	·0259	·0107	1·07	2·14
3	·0461	·0374	·0115	1·15	2·30
4	·0835	·0505	·0131	1·31	2·62
5	·1340	·0660	·0155	1·55	3·10
6	·2000	·0859	·0199	1·99	3·98
7	·2859	·1141	·0282	2·82	5·64
8	·4000	·1641	·0500	5·00	10·00
9	·5641	·4359	·2718	27·18	54·36
10	1·0000				

THEORY OF ARCHES

Fig. 8.

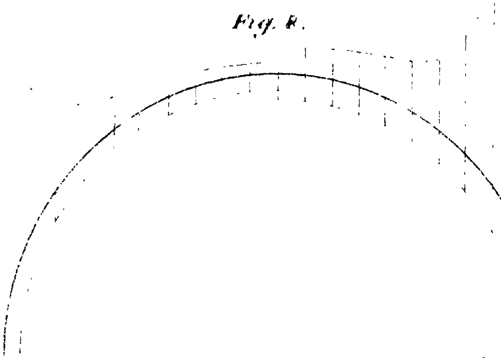


Fig 9.

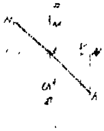


Fig 14.

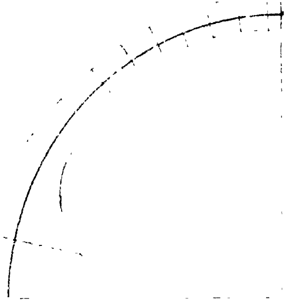
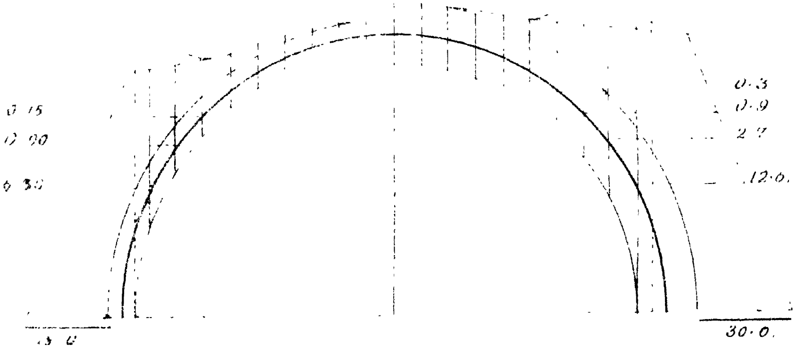


Fig. 10.



This reasoning is believed to be correct for that portion of the arch which is near the crown; for there are no forces acting on it, except its own weight, and the resistances by which it is supported. But as we approach the abutment, another force comes into operation which increases the stability of the arch without adding to its weight. In Fig. 9, let PM be determined by convenience instead of calculation, and be less than OI — MI. Then making IU = IP, there remains a horizontal thrust VN to be balanced. This will be accomplished if we have on the abutment at or above that height, a weight of masonry sufficient to resist the horizontal thrust VN by its friction, the abutment itself being immoveable. Fig. 10, shows the same two semi-arches designed according to these principles. The two vertical dotted lines show the theoretical division between the *backing* which acts directly by its weight, and the *masonry* which acts by its friction. The horizontal dotted lines indicate the points in the Line of Pressure which receive support from this last, and the figures outside give the sectional area which I have calculated is required at each point. The whole horizontal thrust of the arch must of course be balanced by the whole friction developed. It is only further necessary to provide against the backing being overturned, which I have here done by extending its base. This is not advanced as a desirable model to copy in actual construction. It is the development of the theoretical principles on which we should design an arch, to stand even when built of very soft materials, because they would be used to the best possible advantage.

We have hitherto considered *Permanent load* = 0. But to make the arch of use there must be some permanent load. It will form a portion of PM at each point, but the relative values of the different PM will remain as before. Indeed there is no reason why the moving load also should not be included in PM, as we shall see further on.

2nd. *Elasticity of the Materials of Construction.*—The most general notion of elasticity is an effort on the part of the elastic substance to assume its normal shape. Those dimensions which have been extended tend to reduction, and those which have been compressed, to increase. As we assume no adhesion in the materials of the arch, the elasticity in this case includes *compressibility* alone. If the compressibility were great, it would materially affect the Line of Pressure, by *shortening* the arch after it was built. But it is so small that we may neglect its operation in this respect. It affects the Line however through the masonry which acts by its friction. For this masonry exerts no pressure *on* the arch till it is first pressed *by* the arch, which the compressibility of the material does not permit without an *increase* in the length of the radial line, accompanied by a *decrease* at some other point, probably at the crown. Hence the form of the arch undergoes alteration after it is built, in consequence of compressibility. It is enough to direct attention to this fact without attempting to push the investigation further. We cannot prevent the operation of the cause, but we may do something to neutralize its effect in practical construction.

3rd. *Moving Loads.*—We have seen that we may construct an arch so that the Line of Pressure shall bisect the lines of contact under one set of conditions. The converse of this is a problem much more difficult to solve, viz., to determine the position it will assume under different conditions.

If we fall back on the principle of applying more weight to counteract the horizontal thrust as the resultant becomes more nearly vertical, we shall find that the weight required at the springing of a semi-circular arch is nothing less than infinite. Hence we might be justified in concluding that the Line of Pressure will bisect the line of contact at the springing or a little below it, and that this result would not be affected by any change in the moving load which is finite. There is no doubt that this conclusion is theoretically perfectly correct, and there seems to be no reason why the Line of Pressure should not follow exactly the same curve, when we balance by other means the horizontal force for which this infinite weight was required. The subject is difficult to reason upon and not directly profitable, for there is no practical question as to the stability of the lower part of a semicircular arch. And we shall fall into no practical error if we assume that the horizontal distance between the extremities of the Line of Pressure does not vary, whatever may be the variation in the load, and adopt this principle as the ground work of our reasoning in arches of every variety of form—segmental, elliptic, or otherwise.

If a given load be placed in any position on an arch of which this principle is true, we know at once how much of its weight is supported at each end of the Line of Pressure, because we know its horizontal distance from each end. And we shall determine the amount of horizontal thrust due to the load, if we can ascertain the vertical position of its point of support. Now, this is approximately the same as that of the block of masonry on which it rests. If we assume them to be identically the same, we may combine the pressures of the structure, and the moving load, both vertical and horizontal, and so construct a curve which will vary but very slightly from the actual curve of the Line of Pressure. (Figs. 11, 12, 13.) But after having determined the *shape* of the curve, and knowing the *horizontal* position of its extremities, we have yet to fix its position vertically, which we may do, approximately, by taking into consideration the elasticity of the materials. For we know that the pressure on the outside of the arching will be greatest at *a*, and on the inside at *b*, and that the Line of Pressure will adopt such a position as to equalize these greatest pressures. And without entering into calculations it is sufficient to suppose that this is accomplished when the curve at *a* and *b* is equally distant from the line which passes through the middle of the arch ring; by which the vertical position becomes definitely fixed.

We can thus determine the Line of Pressure when a given load is placed on an arch, in which the Line of Pressure would pass through the middle of the arch-ring when there was no load on the structure. Conversely we may design the arch to satisfy this condition when a certain Moving load *is on* the structure, and then determine the position of the Line when any portion of this load is taken away. This is the method here adopted, for the following reason:—

Let n = greatest Moving Load which can possibly be placed on one division of the arch, of which there are 20. Then the whole load may possibly be $20n$, but not more. And as this will cause the most severe test which can be applied, we ought to design the arch so that the Line of Pressure shall pass through the middle of the arch-ring when the load is $20n$.

Figs. 11, 12, 13, show the position of the Line of Pressure, calculated according to these principles under several different conditions.

In Fig. 11, the semicircle shows the Line of Pressure under the maximum load ($20n$), and the other curve shows it when all the load is removed.

In Fig. 12, the sharper curve shows it under a load of $7n$ applied at the crown, the remaining load of $13n$ being removed from the haunches ($6\frac{1}{2}n$ from each side). The disturbance of the Line under this load is a *maximum*, that is to say, it would approach more nearly to a semicircle, if the load were either increased or diminished. The flatter curve shows the Line of Pressure under a load of $9n$ applied at the haunches ($4\frac{1}{2}n$ on each side), the remaining load of $11n$ being removed from the crown. The disturbance in this case also is a *maximum*.

Fig. 13 shows the Line of Pressure when the load is removed from one side altogether, and also from the central division, being the nearest approach to an arch loaded on one side only, which the present method of investigation admits.

These curves are calculated on the hypothesis that the load n is equal to 4 times the weight of the block of masonry whose centre of gravity lies in the vertical radius, which is of course greatly exaggerated. I have done so to show a sensible difference between the different curves, on the small scale on which they must be printed. With the exception of the semicircle they are, as explained, only approximations, but probably close approximations, to the true curve of the Line of Pressure under the conditions indicated.

The effect of *velocity* in increasing the pressure of a Moving load is a consideration closely connected with this subject, regarding which however there is but little known even in the case of iron girders, and still less in any other.

DEPTH OF ARCH-RING.—An arch-stone may be considered in two ways, viz:—1st, As a portion of the arch necessary to its stability; and 2nd, As a portion of the arch which enables it to carry loads.

1st.—In Figs. 6 and 7, I have illustrated the conditions of stability of an arch constructed to stand by itself, without reference to its capability of sustaining any load. The weights of different portions and the pressures exerted by them are there measured by constant quantities, which must bear the same proportion to each other in every case. If, therefore, the material which we select to build the arch be sufficiently strong, the quantity in which we use it is a point of no importance. If the arch can be built of brick, it is just as strong if it be only one brick thick as if it were ten. For every square inch of sectional area to support weight, we have exactly the same number of cubic inches of material to be supported. We may increase or diminish the quantity as we choose, but we can neither increase nor diminish the pressure per square inch.

2nd.—Let us now consider the arch stone as a portion of the arch which enables it to carry loads. If the material be, however little, stronger than is necessary to support the arch, its remaining strength is available to carry loads. Here the depth of arching becomes important, for the excess

THEORY OF ARCHES

Fig. 11.

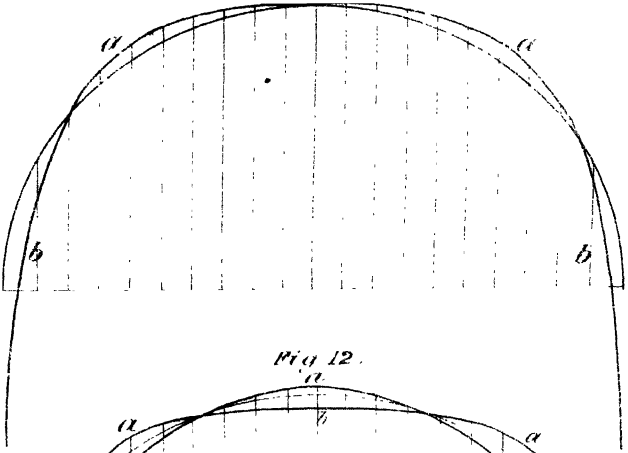


Fig. 12.

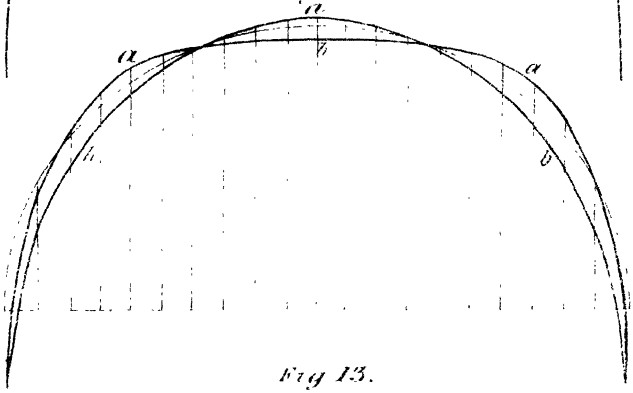
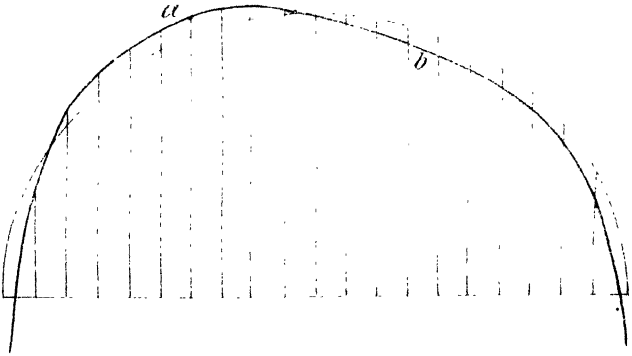


Fig. 13.



of strength in one square inch of bearing surface becomes multiplied by the number of square inches, and the load which the arch may sustain is therefore in proportion to its depth. Moreover, if the load be not all permanent, there must be a certain depth in the arch-ring on account of the disturbance in the Line of Pressure caused by an alteration in the moving load. Therefore an arch-ring which has to sustain any load, requires a certain amount of depth to give it *strength*. And if any portion of the load be variable, it requires a certain amount of depth to give it *stability*.

Although it is necessary to consider the arch stone in these two ways separately, in order to arrive at a correct notion of the duties which it has to perform, we do not require to keep up the distinction any longer. Having assumed the greatest possible moving load, we may combine that with the weight of the structure. Then the arch-ring is of sufficient depth when the two following conditions are fulfilled:—1st, The extreme pressure must not be greater than the material can resist; 2nd, The depth of arch-ring must be sufficient to permit the greatest possible disturbance of the Line of Pressure without bringing it dangerously near to either extremity of any one of the lines of contact.

This phrase "dangerously near" has a precise meaning. When the whole arch is uniformly loaded with its greatest possible moving load of $20n$, the pressure in each line of contact is equal everywhere. When any portion of this load is taken away, the total pressure on each line of contact is diminished, but the Line of Pressure having been disturbed, it is greater at one end than at the other. And if the pressure at either end exceed the original pressure under the load of $20n$, then the Line of Pressure has approached "dangerously near" to that extremity.

The next step towards the depth of arch-ring is to ascertain the rule according to which it ought to vary in arches of different proportions. The object in view is of course to secure an equal degree of stability in each. Now the stability of the arch is affected by the four following magnitudes:—1st, The radius of the Line of Pressure, or (in less accurate terms) of the arch at the crown; 2nd, The depth of arch at the crown; 3rd, The weight of the structure; and 4th, The weight of the moving load. Moreover, it is evident that if we increase the weight of the moving load, or decrease the depth of the arch, we must increase the weight of the structure, or decrease the length of the radius, to obtain the same degree of stability in the arch. This condition does not imply a proportion between the four terms, yet we see that if we make them proportional it will be satisfied to some extent. For, if we make the radius to the depth, as the weight of the structure is to the weight of the moving load, then we cannot increase the load or decrease the depth without either increasing the weight of the structure or decreasing the length of the radius. But it is more in accordance with the principles already laid down to compare the weight of the moving load with that of the structure and moving load combined, which we may call the *whole weight*. Now let $R =$ radius, $D =$ depth, $L =$ load, $W =$ whole weight; and let $l =$ load, and $w =$ whole weight, of an arch whose radius and depth are each $=$ unity. Then the proportion is $R : D :: W : L$, or $\frac{D}{R} = \frac{L}{W}$. Now, the load being the same per foot run for every arch, may be expressed in general terms $L = Rl$, and the whole weight depending on the length of radius and depth of arch-ring, $W = RDw$, whence the general equation becomes

$$\frac{D}{R} = \frac{Rl}{RDw}\,;\ D^2 = R\frac{l}{w}\,;\ D = \sqrt{R}\sqrt{\frac{l}{w}}$$

so that the depth of arch should vary as the square root of the radius $\frac{l}{w}$ being a constant quantity.

I have not been able to assign a value to this constant. The value given in practical treatises is 0·12 for single arches, and 0·17 for arches in series. There is no doubt that these values have been arrived at by careful comparison of good examples; whether the result can be verified by theoretical reasoning is a point I am at present unable to determine. The proportion which should exist between l and w is probably involved in the conditions required to prevent the Line of Pressure from approaching dangerously near to either extremity of the line of contact (see above).

If it be desired to increase the depth of arching from the crown towards the haunches, as is frequently done in segmental arches of large span, the principles of this theory can readily be applied to lay down the rule according to which the increase should be made. In Fig. 6, the total pressure on I from above is HI, and on K is IK. Therefore, the strength of the arch between I and K should be greater than that between H and I in the proportion IK to HI. In Fig. 7, we may at once proceed to the limit, and make the lengths of the arcs cut off be the measure of the depth at the middle of each arc. These arcs give nine dimensions, and we can also find two more, viz., one at the crown where the pressure is only horizontal, and its measure is one division (one-tenth) of the radius, and the other at the springing, which is infinite.

This principle may be applied with advantage in very large segmental arches, in which the rise is not more than one-fourth of the span, *see* Fig. 14, which is drawn according to the following Table, giving the calculated depth for the nine intermediate points when the depth at crown is 1.

Horizontal distance.	Depth.	Horizontal distance.	Depth.
Crown.	1·000	0·6	1·198
0·1	1·001	0·7	1·318
0·2	1·012	0·8	1·522
0·3	1·033	0·9	1·928
0·4	1·070		4·509
0·5	1·120	Springing	infinite.

Points of Rupture.—If the theory now submitted be correct, we shall be able to get rid of these points altogether. An arch designed according to this theory, if it be loaded with its greatest possible load of $20n$, has then no points of rupture. It may fail if the material be simply crushed, but not otherwise; for the Line of Pressure bisects all the lines of contact, and the pressure in each of these is therefore equal everywhere.

Such is the condition of the arch under the *greatest* possible moving load. Therefore, we cannot possibly disturb the Line of Pressure, except by *taking away* some of the load. Suppose we take away all the load from one side of the arch and none from the other; then we have disturbed the Line of Pressure probably to the greatest extent possible. But we have also reduced the moving load by one half. We must now ascertain whether there is any portion of the arch-ring under these altered circumstances which bears a greater pressure that it did at first. If there *is not*, then there is no point of rupture. If there *is*, we may still hope to remedy the defect by an alteration in the proportions of the structure and its load.

To ascertain whether any point of rupture does exist, is simply a matter of calculation, which the theory shows us how to perform approximately. Nor is this all, for the approximation may be used as a fresh point from which to start new calculations, the results of which will be still more near the truth. And I have no doubt that by successive approximations we might attain to any required degree of accuracy. Thus it may perhaps be possible to lay down a certain proportion between l and w (*see* above) which will exclude the possibility of a point of rupture in any arch designed according to the formula $D = \sqrt{}\,R \cdot \frac{l}{w}$.

Summary.—The propositions advanced in this paper are briefly these:—

1*st.*—That it is in our power to cause the Line of Pressure to bisect all the lines of contact between voussoirs, under one set of conditions.

2*nd.*—That we should construct the arch so that these conditions shall be satisfied when the greatest possible load is placed on every portion of the arch.

3*rd.*—That the depth of arch-ring of an arch which does not carry weight is independent of its span or radius.

4*th.*—That the depth of arch which is required in proportion to its radius, depends on the proportion which exists between the weight of the structure and of the moving load, and also in some respects on the velocity with which the load moves; and that the conditions of this latter relation are but little known.

5*th.*—That arches may be designed in which there shall be no points of rupture, properly so called.

A. H. M.

25th June, 1866.

No. CXIV.

RIVER WORKS ON THE GOGRA.

Memorandum on the means employed for the demolition of Sunken Trees and Kunkur Rocks on the River Gogra in Oudh. By Lieut. W. J. Carroll, R.E.

The banks of the Gogra for a large proportion of its course, from the north of Oudh to its junction with the Ganges above Dinapoor, consist of alluvial soil, deposited by the river itself in its higher floods, and liable to be demolished as rapidly as they are formed; in their destruction, villages and trees are carried away, and the latter, when of any size, generally remain fixed in the bed, and become dangerous obstacles to navigation, more especially in the rains.

In addition to this danger, common to all rivers with alluvial banks and subject to severe floods, there are a large number of sunken kunkur rocks and ledges projecting from the main bank where it is formed of that material. Many of these rocks are detached, but the majority of them are connected with the bank by beds of kunkur at greater or less depths under the surface. They are in fact but the more elevated portions of such beds, and the complete demolition of a rock, would, in the majority of cases, involve the removal, not only of such portions as appeared near or above the surface, but also that of large contiguous beds in depths of several feet of water, which is, a much more extensive operation than that generally implied by the "removal of a sunken rock."

During the last two cold seasons, works have been in progress for the removal of these dangers. In the case of trees sunk in the channel, no difficulty has been found that cannot be easily surmounted; but the method that has been used for the removal of those buried in sand below water-mark is still open to improvement. For the removal of kunkur rocks, no large operations have been yet undertaken, and the mode which has been employed in the little that has been done, may, perhaps, also be improved upon. Operations were commenced last year under unfavorable circumstances, and without the time for procuring proper appliances; the means first employed will therefore be quoted rather as examples of what to avoid than of what to imitate; in this way they may be of some service.

It is necessary, in the first place, to describe the general features which produce the difficulty of removing a sunken tree. The current of the Gogra flows in many places 2½ miles an hour, or 3·6 feet a second. This speed is quite common round the edges of a kunkur rock, or between the branches of a sunken tree; in many such places it is much higher than this, and as the pressure of the current is proportional to the square of the velocity, the difficulty of working boats, or placing charges of gunpowder may be considered to increase in the same ratio. The trees are found sometimes wholly, sometimes partially, immersed in the channel, or they are found partly or wholly buried in the sands, and only creating danger in the rains, when the floods rise over their branches and hide them; or they are found thrown up on the sands and not imbedded, or lying fallen on the banks ready to be swept in at the next floods; but wherever they are found, they offer a very indifferent mark for the action of gunpowder. The roundness of the branches and their small surface compared with their strength, the toughness of the roots, and the massiveness of the stem, combine to make the removal of a large tree a tedious and difficult matter. It presents no large and weak surface like the hull of a sunken ship, and it lies usually in shallower water which offers less resistance as tamping to the charge. When broken up, the pieces, often of great weight, have to be dragged in and lifted up upon the high main bank, to prevent their being again carried into the river during floods, and becoming fresh obstacles. The above description applies to the largest class of trees, of which many have been found with stems 10 feet and more in diameter. The removal of a small tree is of course proportionally easier.

The means employed for the blasting of trees last year, in the absence of better ones, were charges of from 25 to 50 ℔s. of gunpowder, contained in tin cylinders, and fired by means of tin tubes rammed with fuze composition, and attached to the cylinders by a water-proof joint. The cylinders were provided with loops of iron-wire projecting from the side, by means of which they could be lowered into the selected spot, by sliding them down bamboos, previously driven in and stayed against the branches of the tree. This method of placing the charge has been retained, as it is found that no moderate weight attached to the cylinders will retain them in their places in a strong current, and because in many places a diver cannot be safely sent down to place the charges.

The mode of firing by fuze tubes was abandoned as soon as possible; it was very inconvenient at any time, and the tubes were liable to break; they were also very uncertain in depths even of 6 feet, and they could not be employed at all in considerable depths.

Bickford's fuze was not procurable at the time, and Brunton's waterproof fuze, though obtained, was not of the quality fitted for burning to any depth under water with certainty. Bickford's fuze has since been obtained from the arsenal at Allahabad, but has also proved uncertain in depths of from 10 to 15 feet. However, I am not aware whether it is of the same quality as that employed in submarine works in England, and denominated Sump fuze; and it is moreover, possible, that the working of the fuze, and the friction against the branches of the tree caused by the strong current in which it was here used, may have rendered it less watertight than it would be in still water.

A third method of firing charges employed last year, and in the present, has been found very effective and,—granted that the cylinder and tube have been properly tested,—it is perhaps the most certain of all. Instead of the thin tin tubes above described, a tube of about three-fourth inch diameter is employed, and soldered into the cylinder near one edge. A thin bamboo lashed to the cylinder and tube secures the latter from being injured, and the cylinder and tube thus prepared and tested can be stored in the magazines ready for use. The testing is done simply by filling the cylinder with water, through the tube, till the latter is full to the top. If the cylinder will stand the pressure of a 10 feet head of water thus applied without leakage, it will bear to be immersed (when filled with the charge) to a depth of 15 feet, or if very tightly filled, to a depth of 20 feet. The charges thus prepared may be placed, as before described, by sliding them down on bamboos into the chosen spot. The firing is effected in the following way, which I believe to be novel. Into the top of the tube, which projects above water, is fixed a fuze which is rammed in a tin tube 9 inches long and of a slightly conical shape. The composition of the fuze contains near its head a pellet of iron of about half the diameter of the lower end of the tube. The burning of the fuze makes the pellet red-hot; it is prevented from blowing out upwards by two cross wires, and consequently when the fuze has burnt out, the pellet drops through the tube, and ignites the gunpowder. A large number of charges have been fired in this way, and no failure has ever occurred through the pellet's not falling or not being hot enough. Charges thus prepared have been used in from 15 to 20 feet of water, and it is manifest that with flexible tubing, such as block tin gas-pipe, that they might be employed in much greater depths and with some advantage where time did not admit of the construction of a galvanic battery. The fuzes should be rammed with ordinary fuze composition, which is a mixture of—

	lb.	oz.
Saltpetre, ...	3	4
Sulphur, ...	1	0
Mealed powder, ...	2	12

and care should be taken that the pellet is always considerably smaller than the tube it has to fall through, and that it is not angular in shape.

But though the above may be a better method than employing quick-match or filling the tube with composition, where, for want of better means, it has to be employed, it possesses all the objections common to the tube system, and is altogether a less workman-like way of proceeding than the use of the Galvanic or Magnetic Battery. The former has not been employed on this river; for though one was constructed, the materials at hand were not sufficient to make it of the required power, and it was put aside for future completion. Full information on the subject is given in Volumes IV., VI., and VII. of the "Professional Papers of the Royal Engineers," new series, and in Mr. Tresham's pamphlet on its employment on the Ganges River works.

The Magnetic Battery has been employed this year with success, and though the mode of using it and the construction of the fuzes are amply detailed in Messrs. Wheatstone and Abel's Report on the subject in Volume X. of the Professional Papers, Royal Engineers, part may be repeated here in order to render the account of the rough but effective fuze here employed more distinct.

The ordinary fuze consists of a wooden plug carrying a gutta-percha core inserted through its axis, and containing two fine copper wires insulated from each other. The core projects three-fourths of an inch from the lower extremity of the plug, and its end is cut off clearly, so as to expose the extremities of the wire, which are one-sixteenth of an inch apart. The upper ends of these insulated wires are separated from each other, and put into connection with two small copper tubes or eyes, which are fixed cross-ways in the head of the plug. These eyes are intended for the reception of the main wires of the battery, and the current in passing has to flow by the insulated wires contained in the core of the fuze, and to leap the interval of one-sixteenth of an inch which separates them. To enable it to do this, the exposed ends of the wires are covered with an explosive composition of feeble conducting power, consisting of an intimate mixture of the following ingredients:—

Sub-phosphide of copper,	10	parts
Sub-sulphide „	45	„
Chlorate of potassa,	15	„

About a grain of this composition is inserted into a small cap of metal foil which is twisted on the end of the gutta-percha's core ; and the bursting charge is contained in a tin tube of a few inches in length, which is fitted on to the end of the fuze plug, and corked at its lower extremity.

When the fuze is about to be used, and has been prepared in the manner described, the end of the wire which leads from the battery is pressed into one of the copper eyes, and another shorter wire is pressed into the other eye, and its upper extremity put into connection with the outer surface of the vessel containing the charge, if it be of metal or with a metal plate attached to it; if it be of wood, the circuit through the fuze and main wire is completed by the water between the surface of the cylinder (or the metal plate), and a metal plate attached by a short wire to one of the poles of the battery, and immersed in the water. The neck of the cylinder through which the fuze has been inserted is of course stopped with a water-tight plug. The charge being thus prepared and placed, the boat containing the magnetic battery is withdrawn to a convenient distance, and the charge is fired by a smart turn of the handle of the battery, which, by causing the armatures of the magnets to rotate before their poles, produces the succession of induction current necessary for ignition. The main wire leading from the battery must be carefully insulated from the water, and the connection of the return wires with the water carefully made. The other connections with fuze and battery need not be made with as much care as when working with the galvanic battery; for, here we have to deal with electricity of higher tension than is produced by any galvanic battery of moderate power.

This description of the fuze and its use, all of which may be found in greater detail in Messrs. Wheatstone and Abel's Report, above referred to, will enable me to dispose of the rough, but effective fuze, here employed in a few words. In place of the wooden plug, a cork is employed, which does the double duty of holding the gutta-percha core and of corking the cylinder. The core itself, instead of the carefully manufactured article above described, may be simply made by taking two pieces, each a few inches long, of single insulated copper wire cut from the coil employed as main wire, cleaning them for about half their length, and fuzing them together by passing a hot iron over the gutta-percha with which they are covered. They are then pressed together till the ends of the wires are one-sixteenth of an inch apart. A shorter interval may be employed with advantage, say one-twenty-fifth of an inch. This core is passed through the cork, and the portion of the fuze wires which have been cleaned and exposed, project above it for the purpose of making connections. One of these, supposing the fuze to be primed and placed in the cylinder, is bent over and put into connection with the metal of the cylinder, generally by folding it up with a little slip of tin projecting from the neck; the other is put in connection with the main wire of the battery.

The priming of the fuze is previously effected by cleaning the inner end of the core, wrapping a small paper cartridge round it, inserting a grain of the magnet fuze composition, and filling the rest of the cartridge with mealed powder slightly rammed, to prevent it and the fuze composition from separating from the end of the wires. The end of the cartridge may be plugged with wax. This small cartridge is quite sufficient as a bursting charge for 50 ℔. charges; but for larger charges, a larger one would be preferable, and could be tied round the cork, which would then be passed altogether into the charge, and other arrangements made for corking the cylinder.

A water-proof substance must always be employed to cover the top of the cork, and protect the connection of the main wire with the fuze which is just outside it, from the water. The substance here employed is that called Kitt composition; it consists of a mixture of the following ingredients, slowly heated together :—

	lbs.	oz.
Resin,	7	8
Pitch,	6	14
Bees' wax,	6	14
Tallow,	1	14

In warm weather it should be kept cool in water, or it becomes too soft to use with convenience; in other respects it is perhaps the best and most flexible water-proofing that can be employed—an important point where any fuze or wire leading from the cylinder is liable to flexure or vibration.

The only precautions that are necessary to be taken with these fuzes, beyond the perfect insulation of the main wire from the water, are that its connection, which is just outside the cork, should be kept out of contact with the surface of the cylinder, and that the cylinder itself should not be washed over with any water-proofing which would insulate it from the water and check the return current. The main wire should also be tied to the cylinder, so as to prevent any strain coming on the fuze or its connections.

The percentage of failures with these fuzes has been exceedingly small. Out of 60 charges lately fired in depths of from 8 to 20 feet of water, and varying in amount from 50 to 450 lbs., there have been only two failures; and these were due probably to defective insulation of the main wire and not to the fuze.

The Magnetic Battery and insulated wire were obtained from the Telegraph Department; the latter is copper of about one-eighteenth inch diameter, coated with gutta-percha. The battery is contained in a box about 14 inches square and 9 inches high. Its great advantages over the Galvanic battery are, that it requires the use of no liquids; it is always ready for use; its power is constant; and it is more compact and less liable to injury. The magnet fuze composition I obtained through the kindness of Lieutenant Wallace, R.E., who employed it in somewhat similar operations on the Hoogly. He had the ingredients prepared, I believe, at the Calcutta Mint, but as it may sometimes be impossible to procure it, it is important to know a substitute. Mealed powder* when moistened to a certain extent is an excellent one. The mode of preparing it is described in the Royal Engineers' Professional Papers before referred to, but may be repeated here. Dissolve chloride of calcium in alcohol till the solution is saturated; steep mealed powder in it till it has thoroughly imbibed the alcohol and with it the chloride of calcium. Dry the mealed powder completely, and preserve it so in a closely stoppered bottle. When required for use, a few minutes exposure to the air will, by absorption, render the powder sufficiently moist for use; this may be known by its showing a tendency to collect together into small granules. It may then be used in precisely the same manner as the sulphide of copper composition. Twelve or fourteen trial fuzes have been fired with this composition in succession without failure, but it has not yet been employed in place of the magnet fuze composition; the trial was considered to prove that it was sufficiently certain for ordinary use. Mealed powder may also be moistened to the proper degree for priming fuzes by simply folding a small quantity in thin cloth, and breathing through it. It is apt, however, to dry too soon, and it is not by any means certain of ignition. Nothing further need be said on the subject of *firing* charges, but it may be added that the charges in common use are 25 and 50 ℔s. ones, contained in tin cylinders. For use in depths of 15 feet and less, these cylinders require no strengthening, but for greater depths they should be strengthened with either stays or rings.

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* Could not be depended on during the hot winds or very dry weather.—W. J. C.

It will render this account more complete, to give a few instances of the demolition of Trees, out of the number that have been removed this year.

In December, a large semul tree, lying 200 feet from the banks at a village called Chupree, was removed by blasting. The depth of water at the root, which lay up-stream, was 20 feet, and the current 2½ miles per hour. A number of separate branches spread out under and above water, and were demolished by separate charges of 25 to 50 ℔s. of powder. The root and stem gave most difficulty; the latter was however broken by two successive charges and separated and dragged to shore by crab-capstans. The root which spread out in irregular masses to a diameter of 20 feet facing the current, resisted a great number of charges, and several cylinders were broken on its projections; others of the charges broke off portions, but brought other new ones up to the surface. The tree was finally demolished after the expenditure of 850 ℔s. of powder. It would have been a manifest saving of time if a 400 ℔s. charge could have been placed near the root, but the strength of the current, and the shape of the root, rendered it impossible.* The crab-capstans employed were roughly made, but have proved very serviceable. They are a convenient mode of obtaining great power, and a few carpenters and blacksmiths can make up one in a day or two.

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* Large boats could not safely be got into position in front of such a tree, and even if they could a cask large enough to contain 400 ℔s. of powder would offer such a surface to the current as to be quite unmanageable; in some positions a cask may be sunk by another plan, described further on.

In February, a large tree lying near the bank at the village of Tajpoor was removed. The stem was a mass of wood of about 10 feet in diameter, and the same in length. The branches were demolished in the ordinary way, but 50 lbs. charges had no effect on the stem. As its upper side projected above the surface of the water, it was ultimately split up by small charges placed in holes bored in the wood. Here also a charge of 300 or 400 lbs., if effective, would have saved time; but neither was there a good position for one, nor do I believe that it would have had any further effect than to throw the stem a short distance to one side or other, as the wood was perfectly sound, and of great strength.

Near the same place a large tree lying half on the bank and half in water was demolished by a 200 lbs. charge followed by a few small ones. The charge was placed in a cask under a hollow of the tree and in the water; the timber directly over the charge was about 12 feet thick, and embraced a palm tree that had grown with it. The timber around it was completely shattered by the explosion, but the palm itself was unhurt. Here the good effect of the charge was due to the timber being rather decayed, and to the good position in which it was placed.

In February, two trees, each 9 or 10 feet in diameter, were removed from the river at the village of Belthfah. The water was too shallow for the use of large charges. On one of them a few 25 to 50 lbs. charges were first employed, and the stem was lifted out of the sand so as partly to project above water; it was then split up by small blasts placed in the wood, and its demolition completed with 25 and 50 lbs. charges. The other tree was removed in the same manner, and in both cases the fragments, which were large, were dragged out by three capstans working together, and hauled up the main bank by an English gyn. Attempts made at the same place to remove a sunken banyan tree were unsuccessful. The roots resisted several small charges, and ultimately a charge of 165 lbs., and a force of 10 tons applied by means of capstans and cables, had no effect in tearing them asunder.

In February, a large tree lying on the sands above the water level was demolished by means of two 25 lbs. charges, fired simultaneously in the following manner:—From the main wire of the battery, a branch was led to each charge, and as the cylinders lay in dry sand, whereas a moist connection is necessary to complete the return circuit, the return wires of the fuzes were connected with metal rods driven down into the sand till moisture was reached. To make the connection more perfect, water was poured over each cylinder and the sand round it. The battery was 400 yards away at the edge of the river. The return wire and plate were immersed in the water as usual. Both charges ignited perfectly simultaneously.

In March a large tree lying in deep water and a strong current at the village of Tickyah, was partially removed. Here also two charges were fired simultaneously, but with little effect; ultimately a charge of 450 ℔s. was sunk and fired in the following manner:—A cask was prepared and tarred, and two rings of hoop-iron were nailed on its ends, so as to project from its sides and allow it to slide down a rod. A bamboo 4 inches in diameter was driven in the best spot available, and the cask was passed on to this by means of the rings; it then stood floating on the water in an upright position and empty, but with the fuzes prepared and inserted. In this case the independent fuzes were employed, as it would have been a difficult matter to recover the cask had one failed. The cask was filled and sunk in its place in a depth of 20 feet, by weights; the bamboo was securely stayed against the tree, and the main wire being connected with one of the fuzes, the boats were drawn away, and the charge fired.* The effect was not so good as might have been expected; some lower branches were separated and the tree was thrown into an upright position, but the stem was quite uninjured. The remaining operations require no notice.

A tree buried in the sand and liable to become dangerous on the shifting of the channel, was attacked in the following manner:—Its position and size were first ascertained with iron sounding rods. The stem was found to be 8 feet under the sand, and 7 feet 9 inches under the water level. A good position being selected, an iron tube 11 feet 6 inches long and 1 foot in diameter, was driven down beside it to a depth of 11 feet by means of a *ringing* engine. The tube was then bored out to a depth of 10 feet with a boring tool 10 inches in diameter, and provided with a leather sand valve. A 50 ℔s. charge was passed down the tube to that depth, and the tube was drawn by a differential pulley hung to the *ring-*

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* In this manner the drag of the current on the cask was rendered harmless, and in spite of it, the charge was successfully sunk into its position under a perfect network of branches, in a place where it would have been quite impossible to bring a large boat.

ing engine. The charge was fired by means of a tin tube and pellet fuze but without much effect. It was neither large enough, nor had it been placed deep enough. The tube should have been driven 12 feet deep, and a 100 lbs. charge placed at a lower level than the stem. Time did not admit of repeating the operation, but the more dangerous part of the tree was removed by other means.

In this operation the Ringing engine was worked in the following way:—The rope attached to the ram was passed down, and through a block at the rear of the engine; it was carried a long distance to the rear, attached to a peg, and worked alternately by two parties, one of which took it up when the other dropped it, and the ram had fallen. In this manner nearly double the ordinary number of blows were delivered in a minute, and the men were not fatigued to the usual extent; but of course a double working party was necessary.

A large tree, lying in the sands near a village called Gyaspoor, was removed by small blasts fired in holes made by means of a lever drill. This drill, which was made up out in camp, consisted of an iron frame, carrying a wheel 1 foot in diameter, and working on a vertical axis. The frame was provided with keys for clamping it on a square iron-rod 5 feet long, and pointed at one end. This rod could be readily hammered into the stem of any tree it was required to bore, and the drill clamped to it could thus be brought to bear in any desired direction—vertical, sloping, or horizontal—the axis of the wheel was pierced to carry a square iron-rod, in the lower end of which the drill bits were fixed. The upper end was pointed, and pressure was applied to it by means of a lever clamped at any required height to the rod driven into the timber. The drill was driven from a 3-feet wheel placed in any convenient position; it was capable of boring 3-inch holes with moderate rapidity.

The preceding examples are sufficient to illustrate the mode in which the demolition of trees has been carried out. A few words may now be said on the removal of sunken Kunkur rocks.

The features that these rocks usually present have been already described, and it only remains to state the means that have been employed in attempts to remove them. The first trials were made last year on a small rock of thin kunkur, lying in from 2 to 6 feet of water, and in a strong current. The apparatus employed was a species of small cofferdam of a portable character, consisting of an outer and inner frame and sheeting;

and including between them 2 feet 6 inches thickness of strong clay puddle. The space enclosed was a rectangle of 4 feet 6 inches by 3 feet 6 inches, the object being to dry a space sufficient for a miner to work in, and drive a shaft down through the kunkur, in which a large charge might be placed and fired. The outer sheeting of the dam was supported by four frames, rectangular in shape, and each 10 feet by 3 feet 6 inches high, braced diagonally and made of 3¼ inches sál scantlings. These frames when bolted together at the angles formed a square enclosure, within which the sheeting was put down vertically in 6 inch widths. The sheeting was supported at the back by longitudinal pieces parallel to the top and bottom rails of each frame, and 2¼ inches within them. These pieces could be put in position after the frames had been bolted together.

The inner framing was constructed in the same manner, only smaller, so as to allow the space between the walls required for puddling. The surface of the rock being very irregular and steep, it was necessary to put down the cofferdam in the following manner :—Two boats were anchored over the rocks, and the outer frames previously bolted together so as to from a square enclosure, were let down into the water. A few pieces of sheeting were then dropped in at the angles, and wedged when resting on the rock. The position and stability of the frame being thus secured, the remaining sheeting and the inner frame were rapidly put in, and the puddling commenced. The attempt to dry the dam failed; it was found that the substratum was sand, and the water came up through cracks with which the surface of the kunkur was covered; but there is no doubt that this kind of dam could be used occasionally with advantage where the material to be removed is solid rock or kunkur underlain with clay; it is very portable, and could be put down and taken up much more rapidly than a dam supported by any arrangement of jumpers driven into the rock.

The next attempt on the same rock was made with boring tools of rough construction. A portion of the kunkur in 4 feet depth of water having been broken up, an attempt was made to bore down, through the substratum, with the object of placing a 50 or 60 ℔. charge at a depth of 6 feet, or thereabouts, below the kunkur. This attempt also failed from the fact of the sandy substratum being too fluid to retain any hole.

Trials were next made on a rock 80 feet long by 50 feet in width, and partly above water; the substratum in this case being clay, the boring tools proved quite effective. The operation of placing and firing the charges ultimately took the following shape:—A 2-inch iron-bar was first driven down into the kunkur to a depth of 6 or 7 feet, and drawn; into the hole thus formed, a small charge of powder contained in a thin cylinder of tin was inserted to a depth of 6 feet and fired. It was found that this charge by its explosion produced a narrow crater in the kunkur about 6 feet deep, and after clearing the hole with a boring tool about 1 foot in diameter, a 50 ℔. charge was readily placed at a depth of 6 feet under the kunkur, whether under or above water. It made little or no difference in the rapidity of the operation whether the kunkur lay under or over water. The hole having been tamped, the charge was fired with the pellet fuze,* producing a crater of about 18 feet in diameter, and 6 or 7 feet deep. In this manner the rock was rapidly blown away to a depth of 6 feet under-water, the whole operation not lasting more than ten days, and had arrangements been more perfect, this time would have been shortened very much.

In the beginning of the present season, attempts were again made on kunkur underlain with sand, and under 3 feet of water. The following method was now adopted:—Boats were prepared with framing, and planks sufficiently strong to bear a heavy strain; they were anchored over the rock with an interval of a few feet between them, and lashed together by cross-ties. A light triangle was erected on the boat, and from it was first suspended a beam of wood, shod with a heavy cast-iron pile-shoe, and slung from a pulley. This was worked up and down like the ram of a Ringing engine till the surface of the kunkur was completely broken up over a small space. On the spot thus broken up, an iron-tube 11 feet 6 inches long and 1 foot in diameter, was now placed, and driven by a ram slung from the triangle, and worked as before described. When driven to a depth of 7 feet, it was bored out, and a charge of 50 ℔s. placed at a depth of 6 feet under the kunkur. The tube was then drawn with a differential pulley, and the boats being removed, the charge was fired by means of Bickford's fuze, producing a crater 16 feet in diameter and 5 feet deep. The operation occupied about 8 hours, but it was not repeated, because the river was too high at the time to make it of any real advantage except as an experiment. Since that time no operations have been undertaken against kunkur rocks, except the following, which was also purely experimental.

The kunkur beds at Hurdee are the most extensive on the Gogra; they lie at various depths, and several rocks jut above the surface, or are just concealed by it when the river is at its lowest level. But whatever their total extent may be, there is no doubt that the removal of about 10,000 square, or 20,000 cubic, yards of the most prominent rocks would greatly improve the channel. It remains to be seen then to what extent the experiments that have been made justify us in supposing that this can be done within a reasonable time and at moderate cost. As in the previous experiments, boats were moored over the rock; this time in from 4 feet 6 inches to 5 feet of water, and a current of more than 2 miles per hour. The other arrangements were the same as before, but as the kunkur here lay to an indefinite depth, and partially mixed with clay, the tube before used was not necessary. A 2-inch iron-bar was driven straight down into the kunkur to a depth of 6 feet, and drawn by means of a differential pulley assisted by block tackle worked from a capstan. The hole thus made was slightly rymed out with an iron tool for the purpose, and a slender sâl pile was driven down, deepening and widening the hole to a diameter of 3 inches;* it was rapidly withdrawn, and a charge of 8 lbs. contained in a tin cylinder was pressed down into the hole to a depth of 8 feet. This was fired, and the hole produced, which was as narrow at the mouth as at the bottom, was cleared out with a boring tool 1 foot 7 inches in diameter and 16 feet long; into this a diver descended, and reported that it was about 2 feet in diameter the whole way down and 8 feet in depth. A charge of 60 lbs. was all that was available at the time, and it failed through the breaking of the cylinder; but this failure in no way affects the principle; moreover other charges were fired successfully under the same rock, in the same manner; but this instance is given, as it was the most successful one in the product of a large and deep shaft.

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* This was one of the earliest operations, and no galvanic or magnetic battery was at hand.

The centre of the above charge was at a depth of 7 feet 6 inches under the surface of the kunkur, and with a further depth of 4 feet 6 inches of water above it. Now, although we have no exact data for the influence of this depth of water, we may presume that it will necessitate a considerable increase of the charge in order to produce the same effect as in air. The charges ordinarily used to produce three-lined craters in earth are calculated as $\frac{1}{4}$th the cube of the Line of Least Resistance, whereas I propose here to employ charges of $\frac{1}{3}$rd cube of L. L. R. On this supposition, the quantity of powder required at that depth to produce a three-lined crater would be 140 lbs; and we may, perhaps, calculate that on an average, charges of 150 lbs. would produce craters of 20 feet in diameter; where the water was deep, they would, perhaps, produce less than this; where shallow, more. Part of the débris from such craters would generally lie about the edges, part would be blown to a considerable distance, and part would fall back into the crater where it would be harmless, being at a considerable depth under the surface. On the débris which lay round the hole, the current would act powerfully, separating the clay and reducing its bulk to less than half the original; the nodules of kunkur themselves would be carried away in the floods, or even if they remained they would be at a much greater depth under water, and could never bind again into a surface as compact as the original. Thus it seems likely that, even were the blasting operations not assisted by dredging, the result would still be to break-up, disintegrate, and reduce in bulk the whole rock, and leave the kunkur in such a condition as to be acted on by the succeeding floods, and to be gradually carried away altogether.

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* In loose kunkur of this description a wooden pile will act effectually as a wedge to widen a hole already formed, but it cannot be driven in the first instance even if shod with iron.

On such an extensive rock surface as that of Hurdee, it would be easy to accommodate three or more working parties,*—we may suppose three,—and it is not too much to assume that, with the proper appliances, each party would fire three charges in a day. Eight charges a day would be a fair allowance for the whole three parties, and supposing such charges to be placed at two-lined intervals, or 14 feet apart, the whole number of charges required to break up a surface of 10,000 square yards would be 462, the quantity of gunpowder about 70,000 lbs., and the number of days in which it could be done 58; but allowing for unavoidable delays and occasional bad weather, it would be well to calculate on the operation lasting three months, which is about the length of the season most favorable for such work.

The cost of the operation may be roughly estimated as follows:—

	RS.
Working parties, including crews of three pair of boats, 20 men each, at an average rate of wages of Rs. 5, .	300
Three Lallas in charge of boats, at Rs. 15, . .	45
Hire of additional boats for carriage of men and materials to and from shore, ...	100
Total .	455 monthly.

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* Each pair of boats would take up a considerable space in order to keep the moorings clear of each other.

As experiment has not yet decided how far it would be necessary to assist the action of the charges by dredging away the débris into deep water, the hire of the three boats, at Rs. 30 per month each, will be added to the above :—

	RS.
Brought forward, ...	445
Hire of three boats for dredging at Rs. 30 per month, each	90
Total, . .	535
Total boat hire and labor for three months, . .	1,605

The work would of course require the presence of an Engineer and a European Overseer, whose salaries however will not appear here. The expenditure on materials would be trifling except that on vessels to contain the charges. This expenditure could be reduced to a minimum by employing either 100 or 200 ℔. charges, in either of which cases, the original powder barrels would be placed in the mines, and no expense would be incurred beyond that of making them water-proof.

If 150 ℔. charges be employed, as here contemplated, the cost of tin cylinders should be added to that of preparing the barrels, as it would be necessary to employ for each 150 ℔. charge, one 100 ℔. barrel, and one 50 ℔. cylinder.

	RS.
Cost of preparing 462 barrels, at 8 annas each, .	231
462 tin cylinders, at Rs. 1 each, . . .	462
Total, .	693
Making a total expenditure during the progress of the works of	2,298

The first cost of preparations and of a stock would be as follows :—

The boats employed for boring and for placing the charges should belong to Government; but their cost would be a charge only against the first operations, as the same boats would answer for all subsequent ones, as well as for any of the ordinary works of the season. Allowing two 150-maund boats to each working party, at a cost of Rs. 1 per maund of tonnage, the estimate would be as follows :—

	RS.
Six 150-maund boats, at Rs. 150 each, . .	900
Decking and strengthening do., at Rs. 50, . .	300
Total, .	1,200

PLANT.

	RS.
Six 2 feet diameter boring tools, at Rs. 50,	300
Three triangles, at Rs. 50,	150
Three differential pulleys, at Rs. 100,	300
Three crab winches, at Rs. 100,	300
Miscellaneous,	150
Total,	1,200
Grand total first cost of boats and plant,	2,400
Grand total cost of labor and materials,	2,298

The above estimate for plant does not include jumpers, hammers, Ringing engines for driving the jumpers,* by which are here meant simply pointed bars of iron, not steeled; blocks and some smaller stores, which in this case happen to be in hand at present. Had these to be included, they would increase the estimate by about Rs. 400.

Taking the figures as they stand, and adding 10 per cent. to cover contingencies and the wear and tear of tools and cordage:—

	RS.
The total first cost of boats and plant will be	2,640
The total cost of labor, boat-hire and materials	2,528

These amounts represent the cost of the operations on a sunken rock, as it would be charged against the sum appropriated for works, and it takes no account of the cost of European supervision and of gunpowder, which would not be so; but where the expenditure of gunpowder is so great, its cost, if it entered the estimate would become by far the largest item. In the foregoing estimate the cost has been worked out by calculating merely from the extent of the surface of rock to be demolished, and it has been tacitly assumed that the charges would in every case reduce the kunkur to a safe depth below the surface. This depth may, and has been assumed as 6 feet, but every additional foot that could be obtained would be of value, and be worth a proportionate increase of expenditure. In order to obtain a clear depth of 6 feet in every case, it would, perhaps, be necessary to use larger mines where the kunkur lay nearer the surface, and smaller where it lay deeper. But it is thought that the average taken, namely, 150 ℔s. for each mine, is on the safe side of the truth.

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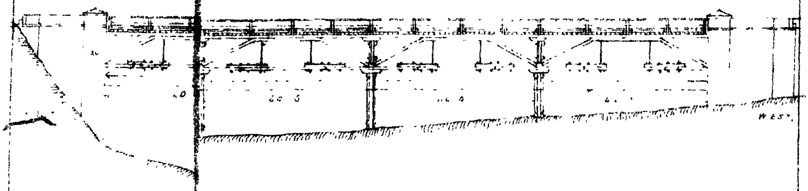
* The jumpers on all the rocks yet tried could be hammered directly down through the kunkur, which of course can be much better done with a Ringing engine than by hand. In the case of block kunkur it would be necessary to work the jumper in the ordinary fashion.

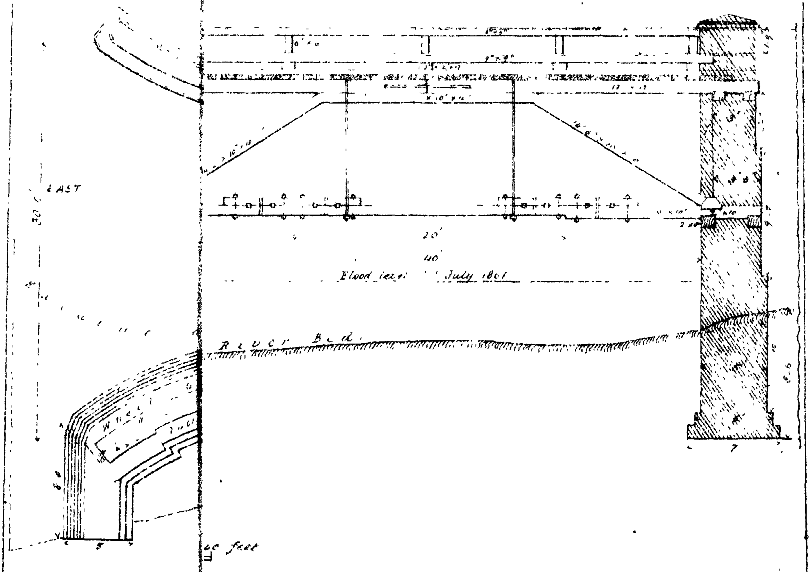
The difficulty previously mentioned, namely, that of entirely dispersing the kunkur thrown up by the explosion of a charge, might be partially obviated by using rather larger charges than those proposed, or by dredging, or by both methods. It is a matter for experiment, as no sufficient data for it exist at present; but it is suggested that it would be economical to work only on the deeper part of a reef according to this method; and where cofferdams could be constructed, to employ them for the removal of all rock within 2 feet 6 inches or 3 feet of the surface, as in such shallow water they would be readily and cheaply constructed. Cofferdams appear to have been employed on the Ganges river works with a certain degree of success, but at an enormously greater cost than that here estimated; there are also certain objections to their use, which cannot be gone into here, and many of the rocks spoken of have a sandy substratum which would not admit of their employment.

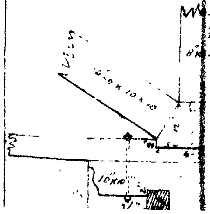
The above description and estimate will answer their purpose, if they be considered to show the feasibility of removing kunkur rocks on a large scale at a reasonable cost. On such a scale as here contemplated their removal is—by the ordinary methods of blasting—by no means a simple engineering problem, and an inspection of the rocks themselves, with masses jutting up here and there and the current racing over sunken beds between them, is not at all calculated to re-assure the Engineer, who has not at the time decided on his means of attack.

W. J. C.

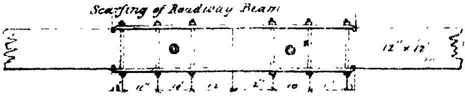


Part of Longitudinal Section of West

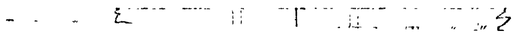




Enlarged Plan
Scarfing of Roadway Beam

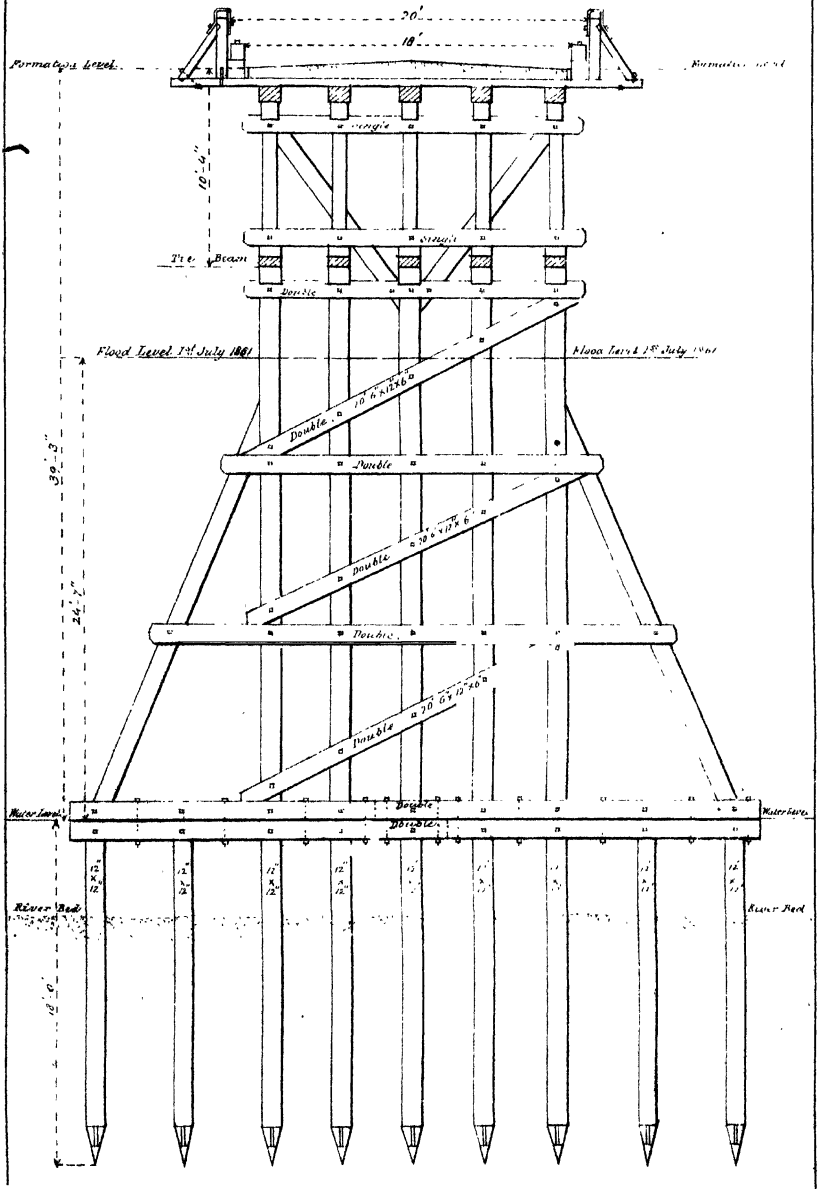


Enlarged Elevation
Scarfing of Roadway Beam



HURROO BRIDGE

CROSS ELEVATION OF PILE PIERS.



ABSTRACT OF ESTIMATE.—(*Continued.*)

s. f.		RS.
76,398·94	Tarring, at Rs. 2 per 100, ...	1,527·978
3,016	Painting, at Rs. 5 per 100, ...	150·800
46	Driving piles at Rs. 15 each, ...	690
	Total Rupees, ...	37,847·007
	Add contingencies, at Rs. 5 per cent., ...	1,892·35
	Total,	39,739·357

ATTOCK,
8*th January*, 1862.

A. T.

No. CXVI.

MANUFACTURE OF IRRIGATION PIPES.

Memorandum on Machine-made Earthenware Pipes for Irrigation.

BY CAPT. W. JEFFREYS, R.E., *Exec. Engineer, Ganges Canal.*

THE complete adaptability of earthen-ware pipes for all purposes of irrigation and drainage may now be considered an established fact. To meet a want so universally felt, steps have been taken by the Government for promoting and developing the growth of this useful description of manufacture. Potteries have been established at certain stations, and the services of professional hands have been obtained from England. We may then safely predict that the day is not far distant when they will come into general use.

The object of this paper, which relates more especially to the employment of earthen-ware tiles for irrigating purposes, is to show the results of the first experiments of the kind which have been made in these Provinces. But before proceeding to consider the processes employed in their manufacture, it is necessary to say a few words on the causes which led to their adoption in the Irrigation Department.

On all canals it has been found necessary to regulate the quantity of water supplied to cultivators, by constructing in the banks of *rajbuhas* (minor irrigating channels) outlets of a fixed section, the size depending on the area it is designed to irrigate. For this purpose wooden boxes or covered-in troughs, (termed *colabas*,) embedded in the rajbuha bank had been used for many years past in these Provinces; but their employment is open to the following objections:—

I. Their great original expense, the cost of each colaba varying from Rs. 5 to 8 each.

II. The necessity of their frequent renewal. For in order that they might be as cheap as possible, common wood such as jamun, semul, mangoe, and others, were used in their construction. They were unseasoned and of a perishable nature, and the consequence was that new colabas had to be supplied yearly; this was a heavy tax on the cultivators.

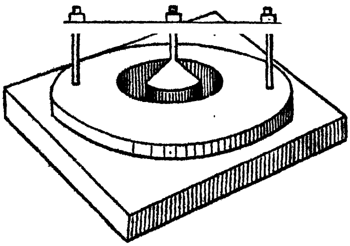
III. For the same reason, that of economy, the workmen nearest at hand (frequently unskilled) were employed in constructing these colabas. They were consequently ill made, of varying section and apt to leak; the result of which was an irregular supply of water, serious breaches in rajbuha banks, and loss both to Government and the cultivators.

IV. In consequence of the yearly renewal of colabas, cultivators came to regard their water-courses as temporary channels, and on receipt of a new colaba often shifted their heads to suit their convenience. Little care was therefore taken in the construction of these channels, which are still in a lamentable state causing everywhere percolation and great wastage of water.

To remedy these evils earthen-ware tiles were first introduced by Mr. Macrone in the Allygurh Division of the Ganges Canal, in 1862. They were thrown and moulded on a potter's wheel and were burnt like tiles in an open clamp. They were made in three sizes, of 8½, 6 and 4½ inches in diameter, respectively. The cost of each joint was from 2 to 2½ annas, so that for 10 joints which were required to traverse the bank of an ordinary rajbuha, a cost of Rs. 1-4 only was incurred. When embedded throughout in lime, 3 inches in thickness, they were found to be tolerably durable; and many can now be pointed out, which have been in use from two to three years without any apparent deterioration. The great advantages derived from the use of earthen-ware tiles, both for economy and durability, soon led to their adoption in other divisions, and it is now believed that the manufacture of wooden colabas has been altogether discontinued.

Although an improvement on the old box, the tiles made by native potters are still very defective. They are necessarily crooked and are not of uniform size throughout. They are but imperfectly burnt, and being porous, they cannot resist the action of water, and must in course of time decompose. A perfectly true sound glazed earthenware pipe would remove all the evils above alluded to, and would be useful, not only for irrigation outlets, but for all purposes of irrigation and drainage to which it may be applied. To attain this object, a manufactory was established at Nanou with a view of making experiments, the results of which are embodied in this memorandum.

The moulding machine consists of a strong wooden vertical cylinder, 5 feet 6 inches in length by 20 inches in diameter, supported on beams firmly embedded in masonry. It is constructed of well seasoned seesum, 3 inches in thickness, secured on the outside with four iron bands, ½-inch in thickness. In the cylinder is a piston worked by a wooden screw, 8 inches in diameter, and at the lower end is inserted a dod or die of the following shape.



The clay, after being previously prepared and worked up to the required consistency, is thrown into the cylinder and pressed out of the dod by the action of the screw. The clay as it escapes is evidently moulded into the form of a pipe.

Below the die is a moveable platform balanced by means of weights attached to ropes running over pulleys, and arranged in such a manner that the resistance offered should just be overcome by the descending clay. When the necessary length of pipe is attained, the action of the screw is stopped; the pipe is cut off with a piece of thin wire and removed to the drying sheds. Being relieved from the pressure of the clay, the platform ascends to its former position, and the operation is repeated. The cylinder full of clay contains twelve 8-inch pipes. In this manner 250 to 300 can be taken out in one day.

The pipes are then kept from four to five days under sheds to dry; if exposed to the sun or wind, they crack or lose their shape.

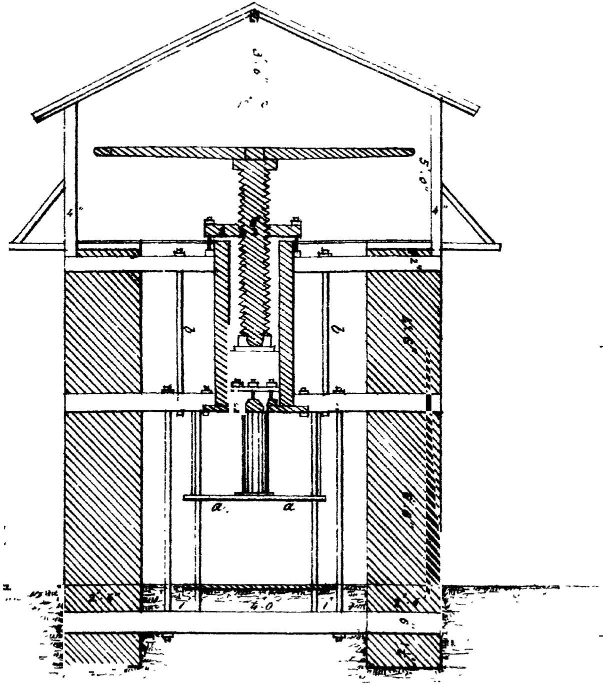
Appended is a sketch of the furnace used for burning the pipes. It has six arched furnaces radiating from one centre, enclosed under a conical shaped dome, 18 feet in diameter; it is supplied with four air holes at top and six fire holes below, as well as two doors. The pipes are stacked in an upright position as closely as they will lie, one course above another, and as the body of the kiln is filled, the doorways are built up with kucha or refuse bricks.

From continued experiments made at Nanou, it was found that it requir-

MANUFACTURE OF IRRIGATION PIPES.

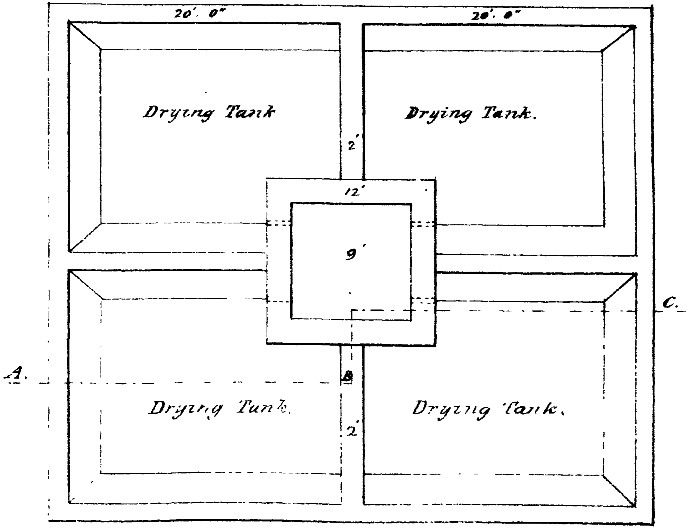
PLATE XXXIX.

Section of Tile Making Machine & House

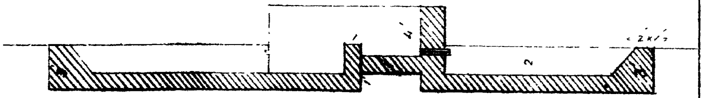


Scale, 6' = 1"

PLAN.



Section on ABC.



Scale 12' = 1"

MANUFACTURE OF IRRIGATION PIPES.

Sketch of Kiln at Nunou for burning Tiles.

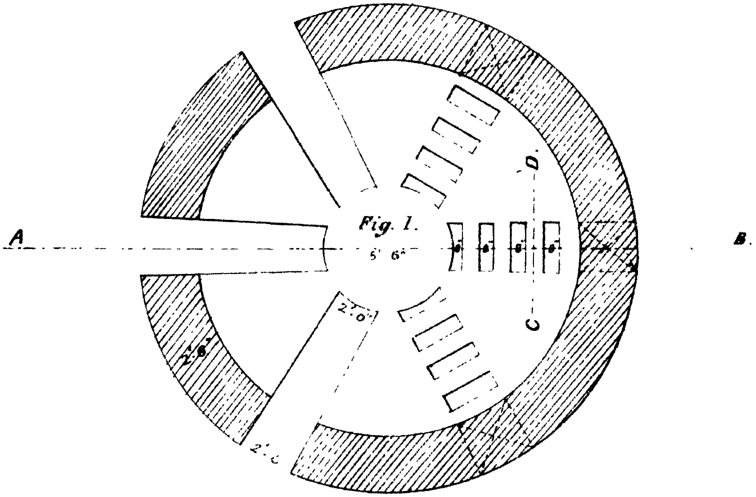


Fig. 1.

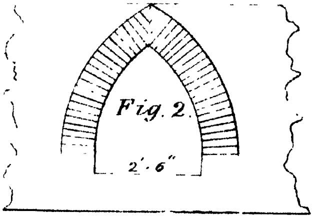


Fig. 2.

SECTION ON CD.

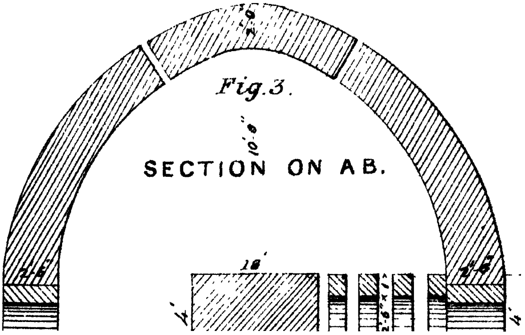
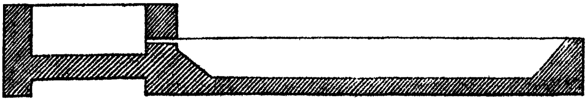


Fig. 3.

SECTION ON AB.

ed 36 to 48 hours to burn the pipes thoroughly. The tiles are gradually brought up to a red heat and maintained so for 12 hours; after which the kiln is raised to the greatest heat possible, that is until the flame and the pipes are of the same color, and this is kept up for 24 hours. The kiln is then allowed gradually to cool, the admission of cold air being carefully guarded against. In the N. W. Provinces the fuel best adapted and most easily procurable is dry babool wood; but where coal can be obtained at a moderate cost, it would no doubt be preferable.

Great care should be taken in the preparation of the clay, as any particles of stone or kunkur left in the clay, are liable to stick in the die and score the surface of the pipe. The most efficient and least expensive method of removing all foreign particles and rendering the clay fit for use is the *blunging* process. It was found most successful, and gave a fineness of texture to the ware which is quite unattainable by pugging or any other method. Two sets of masonry tanks, one raised 2 feet above the other, were constructed, the upper communicating with the lower by means of pipes built into the masonry, 2 inches above the flooring of the former.



The clay was then thrown into the upper tank, mixed with twice its bulk of water, and worked by means of a long wooden spade (termed a *blunger*) until a perfectly smooth pulp was obtained. The mixture was then drawn off into the lower tank, the smaller particles being held in suspension, while the heavier particles fell to the bottom and remained in the upper tank. After ten or twelve days exposure to the sun, the clay was fit for use, without any further labor being required upon it.

When this process is employed in damp climates like that of England, the moisture can only be driven out by artificial means, viz., heat or pressure. This would prove too expensive, except in the manufacture of porcelain or china ware. But in this country where the powerful agency of the sun can be obtained at all times, the desired result is brought about by the simple process of evaporation, and that at no outlay whatever.

Cost of Manufacture.—The pipes were made up at Nanou in lengths of 2 feet, and 3½ and 6 inches in diameter; the expenditure upon them was as follows:—

	Rupees.
Manufacturing 7,800 pipes	704
Firing, including cost of loading and unloading kilns, .	525
Total,	1,229

The out-turn was:—

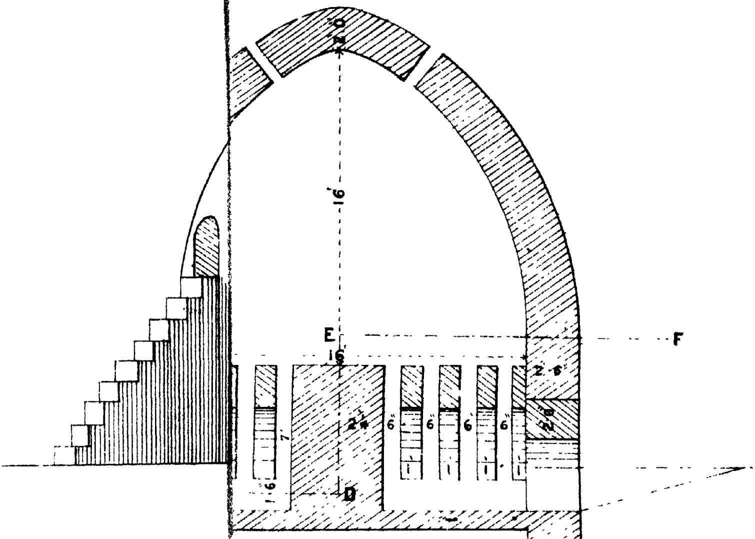
	No. of Tiles.	
1st class tiles, pucka, . . .	3,272	
2nd ditto, more or less peela, but still fit for use,	1,232	4,961
Broken or cracked, ...		2,839
Total,		7,800

From which it will be seen that the cost of each pipe turned out of the kiln was about four annas; but it may be confidently hoped, that as experience is gained, the cost will be greatly reduced.

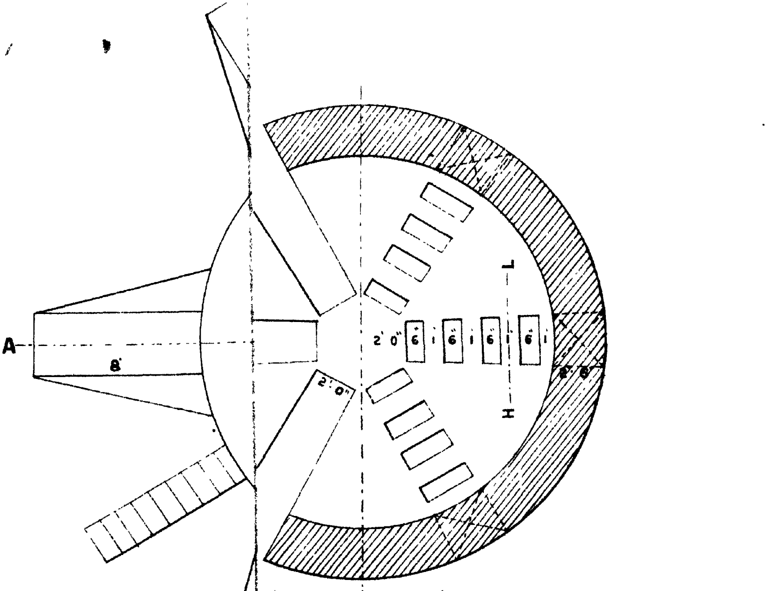
The large proportion of cracked and broken pipes was caused by the frequent falling in of the arches over the flues, while the necessity for rebuilding them at each successive firing added greatly to the expense. This will be entirely avoided in the new form of kiln, a design for which is appended. Being greatly increased in height, it will admit of increased depth of flue and thickness of arch over it; the arches to the furnaces should be pointed, with a rise of 3 feet 6 inches in a span of 2 feet 6 inches; and by using fire-clay for cement instead of ordinary clay, there will be little fear of the arches giving way at the greatest heat to which the furnace will be subjected.

The tiles were made without sockets, as it was found they were not actually required, the joints being rendered prefectly water-tight by embedding them in lime. Sockets can be moulded on the tiles by hand before they are completely dried, and would prove of use in keeping the pipes in their respective places and preventing them from slipping, but in any case the lime must chiefly be depended on for a perfectly water-tight joint.

The great superiority of the pipes manufactured at Nanou over those turned out of ordinary tile making machines, consists in the pressure to which the clay is subjected during the process. When using firm clay (not over moist) it was found that the piston descended one-third of the depth of the cylinder before any clay escaped from the die, showing that the clay was compressed into two-thirds of its ordinary density. The united exer-



SECTION ON AB.



SECTION ON CDEF

tions of 8 men were required to force the clay out of the die, producing a pressure on the clay of nearly 10 tons.

The last point for consideration is the size of pipe best adapted for irrigation outlets. This must in a great measure depend on the areas they are designed to irrigate, and the distance to which it is intended to carry the water. The sectional area of the *paimana* in use under the old contract system is ·4 of a foot, which was calculated by the late Colonel Baird Smith, to give under ordinary head pressure a discharge of 1 cubic foot per second. Although irrigation by contract has almost entirely disappeared, it was thought advisable to adopt this size as a standard in making our first pipes.

The sizes were accordingly fixed as follows :—

Large diam., ·708 feet, or 8½ inches nearly (sectional area, ·4 of a foot)
Small „ ·499 „ or 6 „ („ ·2 „)

A greater number of the smaller size were used, but in many cases they were found to furnish an inadequate supply of water. I am inclined to think that an intermediate size of 7½ inches (sectional area ·3 of a foot) would be the most generally useful. It would be as well however to have at least three different sizes, in order to meet the several circumstances under which they may be required.

The sizes proposed then for adoption are—

No 1. Diam. ·708 feet, or 8½ inches (sectional area, ·4 feet)
No 2. „ ·617 „ or 7½ „ („ ·3 „)
No 3· „ ·499 „ or 6 „ („ ·2 „)

W. J.

16*th January,* 1866.

No. CXVII

ENGINEERING IN THE DERAJAT.

By the Editor.

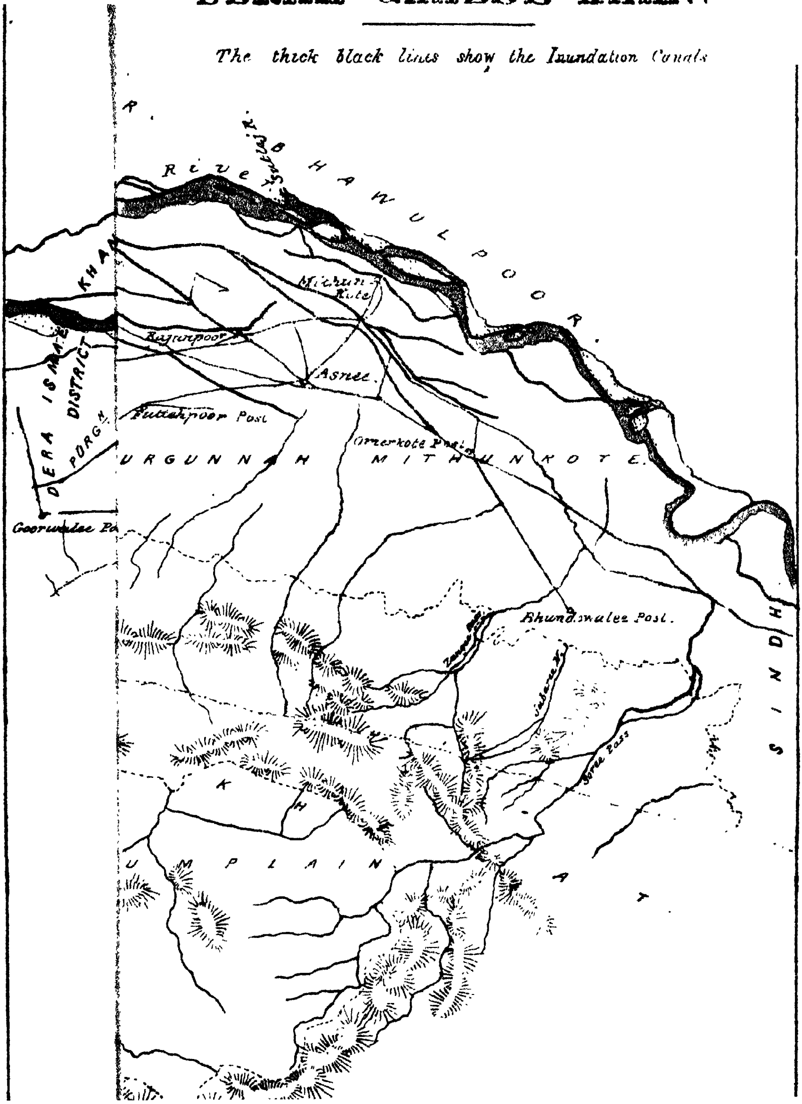
The Deraját is the name given to a narrow strip of country lying to the west of the Indus, between that river and the Suleiman mountains, which form the boundary of our N. W. Frontier in that part of the Punjab; and is bounded by the Bunnoo District and the Sindh Frontier on the north and south sides, respectively. This tract of country includes two districts, those of Dera Ghazee Khan and Dera Ismael Khan, and measures 250 miles in extreme length, with a breadth varying from 15 to 50 miles, as the hills approach to, or recede from, the river.

The physical aspect of the country is peculiar. In the more southern district the river runs between low banks which are inundated during the rains, and whence canals have been cut conveying the water for some distance inland, to irrigate the autumn crops. In the cold weather the river falls and these canals are left dry, their beds being then cleared of the large quantities of silt carried in by the flood waters. But the soil is left rich and moist for the cold weather crop; well irrigation supplies the place of the canals, and a little rain usually falls about February. This part of the country is therefore well cultivated and fairly peopled.

But this description only implies to a small area. As we travel north, the river bank is so high that these inundation canals are impracticable; and again, as we leave the river and approach the hills, the level country soon disappears, and we meet a plateau rapidly sloping from their

Map
OF
DISTRICT
DERAH GHAZEE KHAN.

The thick black lines show the Inundation Canals



foot until it meets the valley of the river. The whole of this upland country forms a strange contrast to the lowlands near the Indus. The soil is a hard stiff clay, stoney near the hills and intersected by numerous dry torrents,—the climate is one of the dryest on the earth's surface, the annual fall of rain being probably about 5 inches,—and the wells are so deep ere the water-bearing stratum is reached, that their construction is expensive, and they can only be very partially used for irrigation.

The soil is too heavy for wheat, and a scanty crop of millet (jowar and bajra) is about the only thing produced. Villages are few and far between, and a coarse scrubby jungle takes the place of trees. The hills themselves are barren and desolate, but in their interior lie more promising valleys, nourished by occasional springs; and here resides a lawless population, who think cattle-lifting more respectable than agriculture, and are always ready for a raid into the plains through the mouths of one or other of the Passes.

A road runs parallel to this dangerous frontier at a short distance from it, and connecting a chain of military posts held by detachments of the Punjab Frontier Force. In support of these forts are the cantonments of Dera Ismael Khan, Dera Ghazee Khan, and Rajunpore, built in the more civilized country near the banks of the river.

For some years after its occupation by the British in 1849, the whole Trans-Indus country was a veritable *terra incognita* to the rest of the Punjab. No ladies were allowed to reside there—English soldiers were unknown, and as there was little to attract anybody in the way of sport, scenery, or antiquities, the country had very few visitors. But to those whose duties compelled than to reside there (among whom was the present writer), the very isolation of the country and the desolation of its aspect had something of a charm. The inhabitants were a fine, manly race, and there was so much to do in the way of physical improvement that the district was interesting enough to an Engineer. There was not a map of the country in existence, nor a mile of road, while the soil was either parching with thirst or being deluged with water. The irrigation canals which formed the very life blood of the district were unsurveyed and in bad order, while many had become choked with silt and had fallen into disuse—the water of the hill streams was turned to little or no account—and the lowlands were subject to severe inundations from the river. The population was scanty and laborers few; while the natives of other parts looked on the Trans-Indus region with dread, and could with difficulty be induced to cross the river. There was not a wheeled vehicle in the whole district, camels being the sole means of carriage.

The first thing to be done was to survey the country and prepare a tolerably correct Map, which was completed in the cold weather of 1853-54. The work was executed by means of polygonal traversing with the theodolite, the details being filled up by the prismatic compass and chain by means of Native surveyors. The map made no pretensions to scientific accuracy, but it showed with sufficient correctness, the course of the river, the lines of canals, and the positions of the principal towns and villages. The survey was necessarily bounded by the frontier road, as it was impossible to penetrate into the hills without an armed force.

The Canals being mapped, various projects were submitted for their extension and improvement, the objects kept in view being to straighten their course so as to lesson the sluggishness of their current and prevent the deposit of silt at the bends—to remove the spoil banks formed by successive clearances further back from the edge—and in several cases to provide new mouths instead of old ones abandoned by the river. It did not appear feasible to design head works of masonry, as such works might be rendered useless by a sudden shift of the deep channel of the river, and might themselves tend to cause such shifts by accumulating and attracting silt. The breadth of the valley of the river, and the consequent immense cost of the operation, prevented any idea of an *anicut* being entertained for the present, by which a perennial supply of water might be secured for the canals. Most of these projects and others allied to them in character, have since been gradually carried out by the present Executive Engineer (Mr. D. Kirwan), then the writer's Assistant, by which the prosperity and revenue of the district have been very greatly enhanced.

A system of forced labor existed for many years for the annual clearance of these canal channels in the cold season, whereby the zemindars were bound to contribute a certain number of workmen, requiting their services with food only. The Government contributed an equivalent in money, but took no cess for the use of the water which was free to all through whose lands it ran. This system has I believe since been modified.

The Hill Streams on which the scanty population at a distance from the river depended for whatever artificical irrigation they had, varied much in size and section of channel. From two only, small perennial streams flowed, and it was curious to see how under the magic influence of these insignificant rivulets, villages had sprung up, smiling harvests waved and trees nestled to their banks; these oases in the desert serving to show that want of water alone prevented the whole district from being a fruitful garden. But the casual torrents of water in the (otherwise) dry hill streams were carefully turned to account. Dams of earth, stones and brushwood, were thrown across their dry channels in readiness for the possible rain, and irrigating channels carefully led from above their sites to the surrounding fields. The furious torrent might burst these flowing barriers in an hour or less; but that short delay had sufficed to turn a supply of water into the dry channels, and below the first dam, a second, third, or fourth was ready to detain the impatient water, and compel it in like manner to leave a portion of its volume for the irrigation of the thirsty soil. Often in this dry climate was the headstrong but welcome guest looked and waited for in vain, while the seed already sown withered and died; not seldom did it come down with such irresistible fury, that dam after dam was swept away too quickly for any portion of the precious fluid to be secured. The sites and strength of these dams had been settled by custom and ancient prescription for many years, and attempts on the part of any zemindar to erect new ones, or render the upper ones unduly strong, led to fierce affray and bloodshed, often terminating in loss of life.

Some of the most promising of these torrents were surveyed, and designs submitted for storing up the water in a more systematic manner, either in tanks formed by damming up the gorges of the passes, or by permanent dams in the streams themselves, thus forming a series of still water reaches at different levels. These were recommended to the notice of Government as experiments well deserving a trial, but the troubles of the Mutiny came on, the writer had to leave for the seat of war, and the projects have, I believe, since been in abeyance.

So complete was the absence of Roads in the district, that the troops marching down in the relief of 1852, had to take guides with them on (what should have been) the main line of road,—and the country was too poor to afford the expensive embanked roads that would have been required over the greater portion of its extent. But a commencement was at least made, and in conjunction with the civil authorities, a system of roads was designed and proper alignments chosen, which should be gradually worked up to as funds were available. This system comprised—1st, A main line of road running the whole length of the two districts, from their northern boundary to that of Sindh on the south, generally parallel to the river, and to the frontier military road near the hills. This line passed through the principal towns, and was chosen so as to ensure halting places for travellers at convenient distances; 2nd, A series of cross roads connecting the Frontier, with the main district, road, at places of the most consequence on each. These roads were laid out from the map, or by means of special traverses made from place to place; they were then cleared for a breadth of 20 or 30 feet, and inequalities of surface tolerably levelled, while temporary wooden bridges were made over the canals. Where the jungle was very thick it was cleared for some distance on both sides of the road. As money was not forthcoming to raise these lines clear of inundation, many of them were annually flooded and repaired immediately after the subsidence of the river. For the passage of the dry hill torrents, the sides were sloped down and paved causeways in some cases substituted as a cheap and efficient makeshift in lieu of bridges, which would have been practically not required for more than perhaps ten days in the whole year.

The Military Forts on the Frontier* were from 10 to 16 miles apart, and consisted generally of a square redoubt enclosed with a mud wall and ditch, and containing barracks for the native soldiers. In one corner was a high square tower which could be isolated from the rest and served as a Keep, to be held if necessary by half a dozen men; it contained the magazine, provisions and water for the garrison. The largest forts were 85 yards square, and were garrisoned by 40 sowars and 20 infantry; the smaller were 50 yards square, and were meant for 25 sabres and 12 bayonets; no artillery was mounted in any of them. The wells in these forts from which the supply of water is derived, are often of great depth; one, a very old well, measuring not less than 220 feet to the water's surface, and another 150 feet. The water of the latter has so bitter a taste that horses will not at first touch it, and this is a characteristic of many wells in this part of the country. I have seen three in a row containing sweet water, and three in another row, scarce 200 yards nearer to the Hills, whose water, though clear as crystal, had a strong saline flavor.

The Deraját contains three small Cantonments, from which the frontier garrisons are supported and relieved; Dera Ismael Khan on the river's bank to the north; Dera Ghazee Khan, also on the river, 120 miles lower down; and Rajunpore, 70 miles still lower, and some few miles inland. The barracks and private houses are generally built of sun-dried brick, which lasts well in so dry a climate; while burnt bricks are expensive, owing to the cost of fuel.

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* *See* the Koorum Frontier Out-post, No. 8 of these papers.

The River Indus, which forms the boundary of these districts to the east, is here a broad, shifting stream, with a sandy bed. The general slope of the bed is about 1 foot per mile, and the minimum cold weather discharge as taken a little above Dera Ghazee Khan is about 14,000 cubic feet per second. At Mittunkote, 70 miles lower down, is the junction of the Punjnud, which contains the united waters of the Sutlej, Beas, Ravee, Chenab and Jhelum. The place, one would think, should be of considerable importance, but Mittunkote is a very small town, or rather was so, for it has since been swept away by the river. The navigation of all these streams is difficult and precarious, owing to the constant shifting of the deep channel, and the districts through which they all flow are poor and thinly populated. Steamers however now go up to Kalabagh, the first rapids where the Indus breaks through the Salt Range, but the bulk of the traffic (which after all is small) is carried in native flat bottomed boats of from 400 to 1000 maunds. A strong south wind blows pretty steadily during the hot weather, greatly assisting the up-stream navigation at that time; in the cold weather there is nothing for it but tracking.

Besides shifting its course and throwing up sandbanks year after year, the river also cuts away its banks very much, and has swept away many a village, and more than one town in this manner. Dera Ismael Khan was seriously threatened about five years ago, and a very interesting series of works was carried out by the Executive Engineer (Mr. Hubert Garbett), which has had the desired effect of diverting the set of the stream, and for the time at least has saved the town and station. Wherever the banks are low, which is the case generally below Dera Ghazee Khan, they are inundated by the river in the rains for a width of a mile or more, the water being checked from further advance by the high canal banks or earthen dams specially constructed. The inundated land is however covered with a rich deposit of silt, and bears abundant wheat crops in the cold season.

A more serious and extensive Inundation however had established itself annually at the time of my arrival in the district, which required some

Engineering skill, and a very heavy expenditure to deal with properly. Twenty miles above Dera Ghazee Khan the river had made a set inland, and a considerable body of water passed through the heart of the district, and interposing between the town and the hills, held a course of 60 miles in length before it rejoined the main stream. The cantonment was not only isolated from the military posts that it had to support, and only saved from destruction by two canal banks which had been repaired and strengthened; but some 500 square miles of the best land of the district was swamped, while the destruction of villages, crops and cattle was very serious—the remissions of Government revenue in one year amounting to Rs. 28,000. It seemed probable too that unless checked, the action of the water would form for itself a regular channel, and the whole of the Indus might take the same course.

Having taken the necessary surveys, and carefully inspected the site, both during and after the flood, a project was accordingly submitted and duly sanctioned. It did not seem likely that any operations on the river with a view of diverting its course would be effectual; they would at least have required to have been continued for several years—they would have cost a large sum of money, and the result would after all have been doubtful. It seemed better, in presence of the immediate and increasing danger, to carry an earthen embankment across the mouth of the inundation, so as to shut it out and turn it back at the site of its exit. The difficulties attending this were the limited time and labor available for the work—the danger of the river's cutting away its bank and eating up to the toe of the bund; while, if carried too far inland, the water in its descent into the valley would accumulate in force and depth—the necessity of crossing two canals without interrupting irrigation and the danger of attack from hill streams in the rear. Nor did any one of these dangers prove imaginary.

The project having been sanctioned, no time was lost in carrying it out. A thousand laborers were imported on monthly wages from Hindustan and the Punjab, and the Civil Officer lent assistance in collecting labor from the district. In raising the embankment much use was made of a simple machine called the *khen*, or scoop, which is also employed for the same purpose in America. It consists simply of a piece of board about 5 × 3 feet, made slightly concave, with a handle on the upper edge, and attached at the two sides by ropes to two bullocks. The ground being first loosened by the common plough, the lower edge of the *khen* is pressed into the soil by the driver's weight, and the bullocks then drag the earth so collected to the side of the bund, where by simply turning over the *khen* on its edge, the earth is deposited.

The length of the embankment was 12 miles, and it varied in height from 1 to 10, or 12 feet; the width at the top was 5 feet; the slope on the water side only 2 to 1; it should have been much more. No turf was available to protect it, and the soil in many parts was a stiff clay liable to crack; all that could be done to consolidate it was to ram it carefully, layer by layer. The two intervening canals were crossed by masonry sluices, the piers of which were built upon wells in the usual way.

The work was barely finished before the river rose, and aided by a strong wind breached it in several places. One or two of the breaches were successfully closed, but the force of the water prevented it in most cases, and all that could be done was to defend the broken ends by spurs and brushwood piling, which was done very successfully, so as to render the amount carried away a minimum. In spite of the breaches, eleven in number, the benefit caused by the embankment was very sensible, the extent of the inundation having been very much lessened. In the following cold weather therefore, the breaches were closed and the whole work strengthened, and the first rise of the river was successfully kept out. In August, 1856, however, heavy and continuous rain caused an inundation higher than had been known for very many years; and which at the same time brought down the hill streams in torrents from the rear. Thus attacked in front and rear, the bund was again breached in several places, and the force of the inundation was so great that part of the cantonment of Dera Ghazee Khan was swept away, and the city itself flooded. For three days the whole population was cooped up in the fort, which was built on very high ground, where they remained until the waters subsided. Communication with the frontier forts was completely cut off, and the loss of property and even life was heavy—the villagers had in many places to take temporary shelter in the date trees where they constructed *muchans*, and remained there until boats were sent to take them off. Very extensive repairs were needed at the embankment; and, fortunately, the inundation during the following year being lower than usual, gave the new work time to consolidate. Since then the work has stood well, and has effectually answered the purpose for which it was designed. The total cost was rather more than a lakh.

One or two practical lessons were learnt during this contest with the river, which it may be useful to record for others in similar cases. The great difficulty of all such works consists in the want of time for the new earth to consolidate before being attacked. No artificial means are so effective as natural consolidation, but it is possible to some extent to lessen the danger. The water-slope should be laid out at an inclination of *at least* 4 to 1: and it is worth going to a very considerable expense to defend this slope artificially. Grass is often not available; or, if at hand, it will not grow at all in some soils; nor in any, without being watered at first, which is often very expensive. It is, however, the very best protection to the slope; but where not available, twisted grass ropes, as used in Holland, laid in long pieces and pegged down, are good, and are generally procurable; or large coarse mats may be employed. Such materials will of course not last more than one season, but that is really all that is wanted. By that time, if there has been a little rain, the earth will have consolidated sufficiently to defy the water unless the bund is over-topped.

Of Engineering materials the Deraját possesses excellent lime, burnt from the limestone boulders found in the dry beds of the hill torrents. Good building stone is doubtless also procurable there, but the carriage is too expensive. Earth for bricks is plentiful enough but fuel is dear and bad. Wood is very scarce, two or three kinds of jungle timber are alone available in the district itself, but deodar and cheer are floated down the Indus or Jhelum from the Himalayas. Labor, both skilled and unskilled, is scarce; good workmen must be imported from the Punjab at high wages. There is a peculiar class of men, called *Odhes*, who migrate from place to place seeking work as beldars; they are excellent workmen, and very willing to take petty contracts; they are, I believe, emigrants from Hindustan. Carriage there is (or was) none available, except camels and a few pack bullocks or donkeys.

Years must probably elapse before the country of which I have been speaking can be rich or populous; but much progress has lately been made—old canals have been opened out, new ones dug, population has increased, the border is quiet, and in short the ordinary results of a few years of British rule are apparent. Much yet remains to be done however—in storing up the hill water—in guarding against the encroachments of the river—in still further improving the canals—and to the young Engineer, fond of his profession, it will for a long time remain one of the most interesting districts of the Punjab.

J. G. M.

No. CXVIII.

BRIDGE FOUNDATIONS IN SANDY RIVERS.

By R. G. Elwes, Esq., C.E., *Executive Engineer.*

It is proposed in the following paper to give some account of a discussion relating to the foundations of the Markunda Bridge, (near Umballa in the Punjab,) which has extended over several years, and will it is thought, be of general interest. It is hoped also, that the Madras Engineers may be induced to give the results of their experience upon the points raised.

A description of the Markunda river, with drawings of the bridge, as it is now being constructed, will be found in a former volume of these Papers (Vol. I., page 442).

The main point at issue is whether, in rivers with sandy beds of unknown depth and considerable slopes, it is on the whole preferable to carry down the foundations to such a depth that no danger need be feared from scour, (sufficient waterway of course being allowed,) without further protection; or, to make the foundations comparatively shallow, and to obviate the danger of scour by floorings or inverts, curtain walls, aprons of boulders or crib work, and similar means. For the sake of brevity the former plan will be spoken of as that of "deep," and the latter of "shallow" foundations.

The Markunda river rises in the Nahun or Sirmoor territory; it is subject to sudden and violent floods, which overflow the country for miles on either side. The bed is pure sand, or sand mixed with equally friable silt, to an unknown depth. Its declivity where it crosses the Grand Trunk Road is 2·72 feet per mile; and the highest *known* flood discharge, about 50,000 cubic feet per second, with a depth of 10 feet, and a velocity of about 5 feet per second. A more detailed description of the river is given in the paper above referred to.

The first design for bridging the Markunda river, of which I can find any account, appears to have been drawn up by Lieut. (now Major) Chesney, R.E., and submitted by Capt. Grindall, Executive Engineer of the Grand Trunk Road, in 1856. The design was for an arched bridge of brick, the arches 36 feet span, the foundations of piers and abutments resting on blocks 20 feet deep, and further secured by curtain walls of blocks above and below the bridge, which were also to be 20 feet deep. Between these curtain walls there was to be a continuous flooring. The foundations for one bay of the bridge upon this design were executed, and have been made use of in the present structure, as will be seen by referring to the plan at page 442, Vol. I.

It seems to have been expected that at a depth of 20 feet, a good stratum of clay would be found, but subsequent trials showed that the bed consisted of nothing but sand, and a mixture of sand and silt, to a depth of more than 40 feet. A few local patches of clay have been come across in the execution of the work, one of which probably misled those who made the original boring.

In forwarding the design, Major Laughton, R.E., then Superintending Engineer, proposed to omit the curtains and flooring altogether, and to carry the foundations down to 40 feet. He objected to the curtains; first, because in order to be safe, they must be carried down to such a depth, that it would be cheaper and simpler to make the pier foundations themselves deep enough to be safe: and also, because the water would be likely to find its way between the blocks, wash out the sand, and so cause the floor to fall in. This prediction, it will be seen further on, has been exactly verified.

Colonel Hugh Fraser, R.E., then Chief Engineer of the Punjab, seems to have concurred in Major Laughton's views; but I have not been able to find his opinion on record.

Colonel W. E. Baker, R.E., then Secretary to the Goverment of India, however joined issue, and in a letter dated December 26th, 1856, to the address of Sir John Lawrence, K.C.B., he makes the following observations:—

"The value of curtain walls and the security of floors protected by them are well ascertained facts. To go no further, the Solani aqueduct is an instance in which both have been adopted, and have stood exceedingly heavy floods.*

"It is indeed precisely in great floods that these adjuncts to a bridge are so important. The irregular action of the current on the river bed at such times is the great difficulty with which Indian Engineers have to deal. It by no means follows that the action of the stream must always extend to such depths as 30 or 40 feet, but that where the protection of floors is not sought, circumstances which are then beyond the control of the Engineer may cause disturbances of the lower bed such as are spoken of.

"It will be a matter for consideration in each particular case, which is the best plan to follow; whether we should carry the depth of the foundations beyond the possible action of the floods, or whether we should protect the bed of the river in the vicinity of the piers by a floor and curtain walls."

Colonel Baker then proceeds to point out "the success which has attended the construction of the great dams or anicuts across the rivers of Southern India on foundations which rest on mere sand, and only go to a depth of 6 or 8 feet." He proceeds: "It is of course not to be understood that such small depths are suitable as a matter of course for bridge foundations in all rivers, but only that there are circumstances under which very moderate depths are sufficient, and that a careful consideration of every element is requisite before coming to any decision on such questions." To this letter were attached some extracts from Colonel Baird Smith's Work on Irrigation in Southern India, which it will be more convenient to give further on.

Shortly after Colonel Baker's letter was written, the mutiny broke out, and the Markunda bridge project remained in abeyance until 1859, when Mr. C. T. Campbell, C.E., who had been in charge of the Tonse bridge while in the service of the E. I. Railway Company, was appointed to re-examine the whole question. He submitted plans and estimates for four alternative designs, viz:—

1. Brick bridge, arches 80 feet span, on block foundations 40 feet deep.
2. Iron Wire Suspension bridge, on brick piers, one span of 500 feet, and two of 250 each.

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* I believe the Solani curtains are blocks 20 feet deep, the intervals filled in with piles to the full depth. The importance of thus stopping up the intervals will appear presently.—R. G. E.

3. Cast-iron Girder bridge, spans 30 feet, on screw piles and cast-iron columns.
4. Iron Wire Suspension bridge, same as No. 2, but the piers formed of eight cast-iron columns, resting on cast-iron screwpiles, 2 feet in diameter.

In the elaborate and valuable report, dated January 1st, 1860, which accompanied these designs, Mr. Campbell strongly advocated the last, on the grounds of economy and minimum obstruction to waterway. In discussing the design for a brick bridge, he gives the following reasons for rejecting the flooring and curtain system. After observing that he proposes to omit these adjuncts, and to trust entirely to depth of foundations for the safety of the bridge, he proceeds:—

"Without for one moment questioning the well ascertained advantages attendant, in many cases, on the use of curtain walls and paved floorings, it may perhaps be doubted whether they would be so advantageous as blocks sunk to a depth beyond the action of the floods in such a torrent as the Markunda, rising so rapidly and tearing along with such force and violence. It must be remembered that it often brings down with it large trees, which, in an arched bridge, will be very apt to accumulate in one or more of the openings, obstructing them and causing the water to rush with redoubled force through the other arches. In such a case scour must ensue, and if it cannot have effect between the piers, it will cut above and below the curtain walls. Such instances I have seen occur before, on a small scale it is true, but still the rule will apply here too; and I have seen in a 15-feet culvert, founded on sandy soil, water, brought to a head by obstructions in the arch, force its way *under* a deep apron and *through* the joints of an invert, the mortar in which was well set. Had the invert been a flat paving it would probably have been blown up.

"Such an event might occur here, the water finding its way under and between the curtain blocks, blowing up and sweeping away the pavings; scour would ensue, and before anything could be done to stay it, the curtain blocks might be overturned, one or more piers undermined, and the whole bridge thrown down. This is of course an extreme view of the case, but it is precisely such views that must be taken into account in deciding a question of this nature."

Mr. Campbell's arguments, however, failed to convince the Government of India. Colonel Yule, R.E., then Secretary to that Government, in a letter dated May 20th, 1861, while acknowledging the care and labor bestowed upon the designs, preferred a modification of the original one to any of them. It was directed that the arches should be made from 37 to 40 feet span, so as to bring into use, if possible, the portion of work already executed. With regard to the foundations, Colonel Yule made the following remarks :—

" Well foundations may be used in two ways, viz., either by employing the wells as piles and sinking them till we reach a firm stratum; or where such a stratum lies very deep (as in the present case), by establishing a practically impermeable barrier under the bridge in the shape of flooring and curtain walls, to secure the foundations from scour. The last method has often been used on this side of India, (without, it is believed, a serious example of failure,) but it has never been so fully taken advantage of as in the Madras Presidency. There, as has before been precisely pointed out in correspondence on this very subject, well foundations of bridges, in sandy beds of unknown depth, are not sunk more than 9 or 10 feet, often less; the wells themselves being also of very rough and crude structure. Yet they stand safely; and it is mainly owing to the cheapness of this construction that so many noble bridges have been built in the Madras Presidency, over rivers such as we habitually leave unbridged, on account of the estimated cost. Indeed, the experience of Madras shows that well foundations of 6 feet in depth, on sandy river beds having a slope of 3½ feet per mile are secure.

" It is not necessary to go to such an extreme, in order to secure the advantages of a desirable economy. In revising the design, the depth of the pier foundations should be limited to 15 feet, and that of the curtains to 12. Round wells should be used instead of square blocks. They are more easily and rapidly sunk, and are just as good for the purpose now in question. But in the upper curtain wall the greater continuity of long rectangular blocks will be an advantage. The curtains should be kept well clear of the cut-waters of the piers."

Upon these instructions, the design given in Vol. I. of these papers, was prepared by Mr. W. Purdon, M. Inst. C.E., who had been appointed to the charge of the works. Round wells were used in the upper as well as in the lower curtain wall; in consequence of a difficulty in procuring wood suitable for block *neemchucks*. In the lower curtain, continuity was sought to be obtained by putting down two rows of wells, those in the second row being placed opposite the interstices of the first. The works were commenced in 1861, and up to the beginning of 1865, nothing occurred to throw doubt upon the security of the plan adopted, so far as the curtains were concerned.

In consequence, however, of the ease with which the pier wells were countersunk to the prescribed depth, it was thought desirable to sink them somewhat further, lest they should be unable to bear the weight resting upon them. It will be seen on referring to the drawings, that each pier rests on ten wells of 5 feet diameter, giving a wide base* independently of the concrete between the wells; but it was thought possible that the semifluid sand might yield lightly to the pressure, and so endanger the arches. The Government of India, in discussing the Excutive Engineer's proposal to sink the pier wells to 20 feet, observed as follows :—

"They (the pier wells) were, as settled by the Government of India, to be only 15 feet deep, instead of being sunk as usual in the N. W. Provinces, until they will descend no further. This small depth, when combined with a well protected flooring has been proved by Madras experience to be perfectly reliable, and it was considered an object to have an example on this side of India. Accordingly, the order was issued, and the wells have been got down to that depth; but with such ease, it is stated, that a further depth of 5 feet, considered 'wiser because safer,' has been ordered.

"Bearing in mind that works on wells only 6 feet deep, have succeeded in Madras in rivers with sandy beds, sloping 3½ feet per mile, a safe margin for the experiment was allowed, in ordering wells 15 feet deep in sand, the slope being certainly under 4 feet per mile.

"The Executive Engineer suggested this greater depth of 15 feet, because† he deemed that the river channel being contracted by the contemplated bund and the bridge piers, there may, in a flood, be a scour of from 5 to 8 feet of the silt deposited on, or rather forming the upper stratum of the bed. But if a scour takes place and foundations be endangered, the curtain wells will certainly be affected before the pier wells are. If the curtains go, the flooring also will go, and the pier foundations will then be exposed to an action they were never intended to, and certainly would not, withstand. * * * * * * *

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* The pressure on each square foot of the wells supporting the piers, including the "hearting" of concrete is 3 tons.

† The chief reason seems to have been the doubt as to the bearing power of the wells in soft sand as noted above. The bund referred to has not been executed as yet, and will not contract the waterway.—R. G. E.

so that if 20 feet depth of well is necessary anywhere, it is in the curtain wells, which protect the remainder.

"It has not been overlooked that the depth of the curtain wells originally ordered, compared with that of the pier wells, is open to condemnation on the grounds now laid down, and it may with advantage be noted that in Madras, the bed of the river would in most cases, be protected to a greater distance below the bridge than 14 feet, whilst there is generally plenty of stone at hand for tail protection there."

By the time these orders reached the Executive Engineer, one row of curtain wells had, I believe, been sunk to 12 feet and filled in. They could not therefore be lowered; the greater part of the pier wells also had been sunk to 15 feet; and had stood for a rainy season. Upon recommencing work, it was found that they had become so earth bound that they could scarcely be moved; and thus, while the intention of sinking them to 20 feet was frustrated, the necessity for doing so was proved not to exist. Difficulty was found in getting even new wells down to 20 feet, and eventually the pier wells were left at various depths, according to the resistance experienced, from 15 to 20 feet.

It has been mentioned that only one row of curtain wells on the lower side were put in at first. From motives of economy, the second row was deferred, but unfortunately, the necessity of taking other precautions, such as piling between the wells, to make the single row a really imprevious barrier, does not appear to have been sufficiently foreseen. The spaces between the wells were intended to be filled to a depth of 5 feet, with 3 feet of concrete, and 2 feet of masonry. From the high level of the water in the bed, or some other reason, it seems to have been impracticable to put this protection to its full depth at all points: in some places it was found to be only 3 feet, or even less.

The piers had all been built before the rains of 1864, and now the effect of the bridge in producing a scour of the bed might be expected to become visible. A gradual deepening of the channel had been taking place since 1859, when the zero of the gauge (the level of the flooring) was 2 feet below the lowest point in the bed of the river. In 1864, the lowest point of the bed was almost level with the zero, but in that year the highest flood was only 7·5 feet, the waterway was clear, and the state of the bed favorable. No scour was observed.

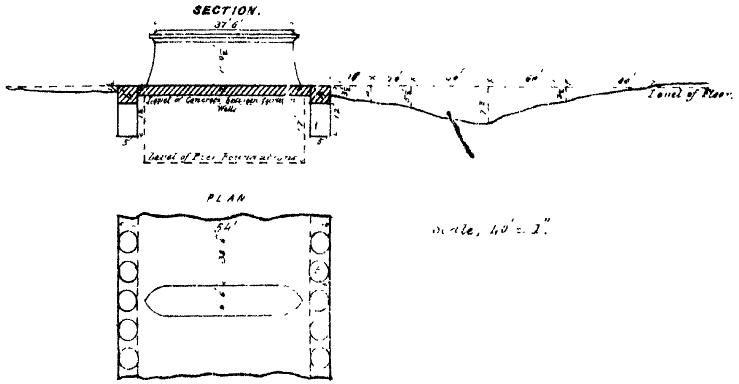
It must be remarked here, that the effects of a flood in the Markunda depend rather upon the suddenness with which the waters come down, and the state in which they find the bed, than upon the extreme height to which they rise. The channel is a wide shallow shifting bed, constantly getting choked by heaps of drift sand and banks of silt, which are sometimes thrown up to a height of 5 or 6 feet by a single flood, a corresponding encroachment taking place on some other part of the bank. The floods occasionally come down with extreme suddenness, so that people overtaken in the dry bed of the river are drowned before they can reach the bank. One flood had reached a height of 5 feet upon the flooring, which had previously been quite dry, in almost five minutes from the appearance of the first trickling stream.

In the spring of 1865, shortly after I took over charge from Mr. Purdon, who was removed to a higher appointment, a winter flood of about 4 feet came down, and being slightly obstructed by the masonry piers which supported the centerings on one side, and by large deposits of silt on the other, scooped out a hole about 4 feet deep (probably much deeper during the height of the flood) immediately below the curtain wall opposite two of the arches. Some sand was washed out between the curtain wells, which are 15 inches apart, and the connecting portion of concrete and masonry, which happened to be only 3 feet deep at this point, fell in. The edge of the flooring was taken up, but the injury did not appear to extend beyond the back of the curtain wells. The hole was filled up with concrete and masonry; and to protect the green work during the rains, a row of sheet piling was driven about 10 feet from the edge of the flooring in front of the two bays where the scour had occurred, secured by waling pieces to guide piles 12 feet deep. This protected the place for the time, but the accident set me thinking what would be the effect of a maximum flood of 10 feet in depth coming down suddenly, with the channel so blocked up with silt as it usually is. The section attached, taken 500 feet above the bridge, shows the state of the bed in February, 1866. The average depth of silt is 4¾ feet, and the area of waterway between the bed of the river, the abutments, and the springing line, 12 feet above the flooring, is only 9,041 superficial feet, which with the normal velocity of 5·5 feet per second, gives a discharge of 49,725 cubic feet. Now, a flood rising only to 10 feet above the flooring requires a discharge of very nearly 50,000 cubic feet. It was evident, therefore, that there must be a great heading up of the water at the bridge, until the river

BRIDGE FOUNDATIONS IN SANDY RIVERS.

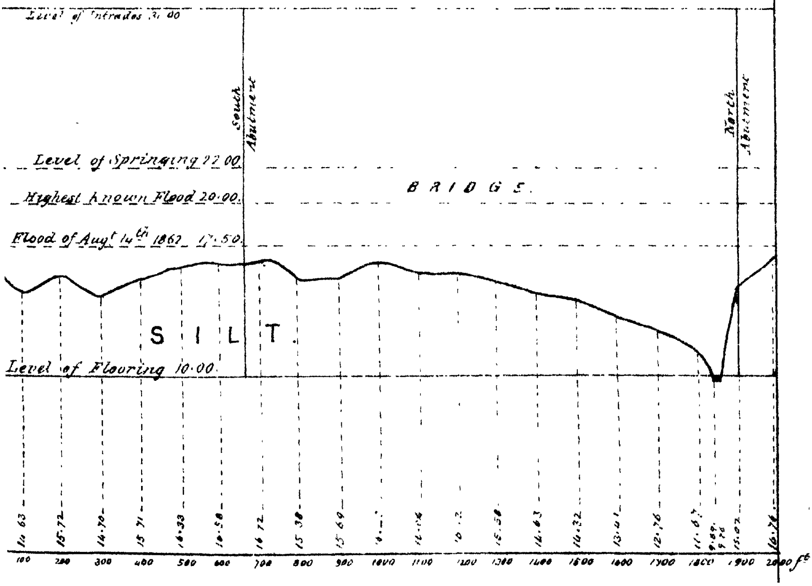
MARKUNDA BRIDGE.

Sketch, showing Scour produced by a Flood of 7.5 feet August 14th, 1862.


SECTION.
37' 6"
Level of Concrete between Screw Wells
Level of Pier Foundations
5'
5'
12
Level of Floor.
PLAN
54'

Scale, 40' = 1".

Cross Section of Channel taken 500 feet above Bridge, Feb 26th 1866



could cut a passage for itself through the silt. If a slight heading up, probably not exceeding 3 inches of a 4-foot flood produced such unpleasant effects, what might not be expected from a 10-foot flood, with a fall, for a short time, of 2 feet through the bridge?

In the rains of 1865, the highest flood was about 7 feet on the flooring, and the effects left on its subsidence are shown in the annexed section. It will be seen that there was a scour of 1½ feet on the *upper* side of the flooring, and a hole scooped out on the lower side, 3½ feet deep at the edge of the floor, and 7 feet deep at a distance of 40 feet from the edge. This hole was gradually silted up as the water went down; it was measured when there were 3 feet of water on the floor; probably in the height of the flood the hole was much deeper. The scour was no doubt increased by the obstruction of the masonry supports for the centres, of which there were five in each arch, 3 feet thick and 4 feet high (less than the average depth of silt). But the obstruction of these was as nothing compared to that of the silt banks, which must be looked on as a normal feature, for though swept away more or less in the height of each flood, they are always reformed as the waters go down, and ready to dam up the first rush of the next flood.

It appeared to me, that had the foundations of the Markunda bridge been only 6 feet deep, this flood would have settled the question by carrying away the whole structure, and it became a matter of some interest to investigate the Madras data, which had made so much impression on the Government of India. About this time Major Crofton's Report on the Ganges Canal reached me, and I proceed to give some extracts bearing upon the point at issue. It is hardly necessary to remind readers that the slope of the Ganges canal, in the sandy parts, is only 15 inches per mile, that the depth is only 7 feet, the channel uniform and straight, free from drift, sand hills, or silt banks, and with a stream regular and constant, instead of a succession of *dèbacles*. Here is what Major Crofton says as to the state of the bridges:—

"Holes have been eroded in the bed below the Jowalapoor bridge, and all the falls, to the depths shown in the section. In one instance, at the upper Bahadoorabad Fall, the erosion extends considerably below the bottom level of the foundations. No injury, however, has resulted from this to any of the masonry works, *the talus of boulders and cribwork*, originally attached to each on the down-stream side, having transferred the excessive action of the current to a sufficient distance from the works themselves." Para. 4.

Again: "Very deep holes have been formed, as the longitudinal section will show, below all the masonry works in the sandy tracts; in some instances as at the Hafiznuggur falls and the Bailra bridge, extending several feet lower than the bottom of the foundations, but in no case has this affected the stability of the masonry works; *the talus of boulders or kunkur has everywhere proved its efficiency as a means of protection.*" Para. 13.

It is abundantly clear from Major Crofton's Report, that had the bridges on the Ganges Canal been protected by curtains only 6 feet deep (the foundations being of no greater depth) *without any talus*, many of them must have fallen in long ago. It is true that the velocity through these bridges is somewhat higher than that due to the original slope of the bed and the obstruction of the piers, alone, because the general erosion of the channel has converted the bridge floorings to some extent into sunk weirs. But the increase of velocity, due to this cause, cannot be great, for Major Crofton's states (para 29)—"that the heading up is very slight in every case; at some bridges it could hardly be detected by the levelling instrument." And whatever it may be, we have the same evil to contend against at the Markunda bridge, where the flooring is already about 6 inches above the level of the bed above and below bridge; an evil which will increase as the erosion of the channel goes on, until the slope of the bed has accomodated itself to the new regime of the river.

If then, as experience shows, very shallow foundations without a talus are unsafe in a stream with all the advantages of the Ganges Canal, they cannot be safe in a torrent like the Markunda, or those in Madras, with slopes of 3 or 4 feet in a mile. It is now time to examine the deductions drawn by Colonel Baird Smith from the works in Madras, which have evidently all along influenced the Government of India in prescribing the the mode of dealing with the Markunda. These deductions, quoted by Colonel Baker in the letter above referred to, will be found at pages 43, 44, of Colonel Smith's "Report on Irrigation in the Madras Provinces." I beg the reader's particular attention to the parts which I have italicised.

"*3rd.* That in rivers with beds of pure sand, and having slopes of 3½ feet per mile, such dams* may be constructed and maintained at a moderate expense.

"4th. That the *elevation of the beds* of the rivers above the dams to the *full height of the crowns* of these works is an inevitable consequence of their construction, and that no arrangements of under-sluices has as yet been effective to prevent this result.

"6th. That in pure sand, acted on by the current due to a fall in the river bed of 3½ feet per mile, and exposed further to the action of floods from 12 to 15 feet deep, well foundations in front and rear, of 6 feet in depth, have been proved, by an experience of 15 years, to be safe.

"7th. That with a vertical fall in rear of the dam from 5 to 7 feet in height, a thickness of 2 feet of brick masonry and 1 foot of cut stone, with a breadth of from 21 to 24 feet for the apron, have proved sufficient to insure stability, the only further protection required being *a mass of rough loose stones*, about 9 feet in width and 4 in depth. The loose stone apron should at first have a breadth equal to 1½ times, and a depth equal to two-thirds the height of the dam. The action at the tail of the work, *leading to constant additions to the loose stone*, soon deranges these proportions, and they are given only as guides in the first instance.†

"8th. That the *main security of the dam* depends upon the efficient construction and careful *maintenance* of the apron."

In the first place, these deductions apply solely to dams or anicuts, and Colonel Baird Smith makes no reference to bridges in this connection. What he does say about the Madras bridges when describing the Gunnarum aqueduct, will be quoted presently. Now the curtain and flooring system is open to two main dangers. First, that of the water finding its way between or under the curtain wells, and either blowing up the flooring or washing out the sand from under it. This is the objection urged by Major Laughton and by Mr. Campbell. Secondly, there is the danger of holes being scooped out by the scour below the bridge, which may extend back below the bottom of the curtain, and cause it to fall in. Of this I have quoted illustrations from the Ganges Canal.

The first danger can hardly occur to an anicut; the action of the dam raises the bed of the river to a level with the crown of the work, so that the water must find its way down $7 + 6 = 13$ feet to get under the upper curtain, which is further protected by an up-stream apron. The solid body of the dam itself, and the strong apron of masonry 3 feet thick, are sufficient to protect the work from being blown up or undermined. The danger of scour below is provided against by the talus of loose stones, which has to be continually watched and renewed. This talus Colonel Baird Smith declares in the case of the anicuts, as Major Crofton in the case of the Canal bridges, to be the main security of the work. It is the omission of this essential protection which appears to me to render the design laid down for the Markunda and other large bridges so insecure. The talus or apron alone, however is not sufficient, unless the curtains be made really impervious, so that there is no danger of the flooring being undermined. For this purpose it would be better to use blocks, instead of wells, both up and down-stream, and to fill up the spaces beween the blocks with accurately fitted piles.

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* That is, dams (anicuts) similar to these in Tanjore, for distributing the waters of a river, at the head of its delta, among its several branches.—R. G. E.

† Perhaps some Madras officers will kindly state the size and description of stone used for these aprons, and the extent to which they require renewal every year.—R. G. E.

I have not been able to find any description of a bridge in Madras, built over a river with a sandy bed on a slope of 3 or 4 feet to the mile, upon shallow foundations, even with the protection of a stone apron. The Gunnarum aqueduct, which is sometimes quoted as an example, is not a case in point. Colonel Baird Smith gives a description of this aqueduct.* He does not mention the slope of the branch of the Godavery river over which the work is constructed; but I gather from his report that the average slope of the high floods of the main river is from 15 inches to 18 inches per mile; also that the general slope of the country longitudinally is about 12 inches per mile. Probably the slope of the bed under the aqueduct does not exceed the latter amount, and it appears from Major Crofton's Report on the Ganges Canal, para. 131, that the stream is a tidal one, the tides rising and falling 3 or 4 feet at the site of the aqueduct—where there is consequently a considerable break-water on the flooring. The aqueduct consists of 49 arches of 40 feet span; the springing line is 11½ feet above the flooring. The piers rest on wells 8 feet deep: the curtain wells up and down-stream are 4 feet deep. Above and below the curtains are aprons of loose stone, the upper one 5 feet, the lower one 16 feet, wide. The depth of these is not given. The soil is described as "sandy."

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* (Irrigation in Madras, pages 111, 118.)

Colonel Baird Smith evidently entertained grave doubts of the wisdom of pushing economy to such an extreme, independently of the objections to the contracted waterway of this aqueduct. He says: "It seems to be possible to secure foundations on the rivers of Southern India, *with their very low slopes*, by means which, with our own experience of the rivers of Northern India, we should be justified in pronouncing utterly inadequate, and with which in fact we should never dream of operating, since *they would inevitably fail on the first serious trial.*" It is evident that Colonel Baird Smith, never intended to apply the results of the Madras *anicuts*, to the case of *bridges* in Upper India, where the conditions are so different.

The conclusions to be drawn from the facts above described were sufficiently obvious. First, that far too much stress had been laid on the success of shallow foundations in Madras, and that the plan had been applied under circumstances and conditions quite different from those of the anicuts which had furnished the idea; Secondly, that the main and most essential element of the Madras system, the talus or apron, had been entirely omitted; Thirdly, that the foundations of the bridge could not in their existing form be relied on, and that some further protection was necessary.

Several remedial measures suggested themselves; the first being to sink the second row of curtain wells opposite the interstices of the first, as originally intended. This was soon given up, for the following reasons:—As the flooring had been put down, the sinking of a second row of wells so close to the edge would inevitably draw out the sand from under it, and thus give rise to the very evil it was desired to remedy. Moreover, it appeared that the greatest scour occurred opposite the ends of the cutwaters or starlings, being caused by the "swirl" or eddy of the water meeting below the piers. The edge of the flooring was so close to the cutwaters, that the additional width of 6 feet aided by another row of wells would give no protection against this action, and it seemed desirable to extend the flooring further down stream. Lastly, it was considered that a curtain wall in such a stream, unprotected by any apron, and exposed to a scour such as had already begun to show itself, could not be safely made less than 20 feet deep. To sink wells 3 or 4 feet deeper than those on which the piers rest, at a distance of only 7 feet clear from the end well of the pier, was not to be thought of.

Cribwork, filled with brick or slag, would be as expensive as masonry and less efficient.[*] No boulders were available for a loose apron, and for the above reasons it was recommended that the flooring should be extended 40 feet down-stream, by an apron of concrete 2 feet thick, terminated by a row of blocks 12 × 6 feet, sunk to a depth of 20 feet, with intervals carefully filled up by piling to within 5 feet of the top, which space was to be occupied by a continuous platform of masonry. It was also recommended that the curved wing walls which had been given in the original design but afterwards omitted, should be restored on the up-stream side of the bridge, as there was a considerable tendency to cutting along the face of the abutment on either bank. The cost of the proposed additions was estimated at Rs. 1,03,782.

In a report, dated 31st December, 1865, which accompanied a revised estimate for the bridge, including the protective works described above, I gave the following summary of the question of foundations :—

" If, as appears from the experience of the Ganges canal, very shallow curtains *without a talus* are not safe in a sandy bed with a fall of only 15 inches per mile, and a depth of 7 to 8 feet, *à fortiori*, they cannot be safe in a torrent like the Markunda, or those in Madras, with slopes of 3 to 4 feet in the mile, and floods of 10 to 15 feet in depth. If, indeed, the curtain be protected by an apron of boulders or cribwork, carefully watched and continually repaired, as seems to be the practice in Madras, the system would, no doubt, be safe; and in situations where suitable materials can be obtained cheaply, it might be more economical than the alternative of very deep wells with no flooring at all. But the Markunda Bridge, as observed by the Government of India, is neither one thing nor the other. *Without* a talus (which owing to the scarcity of wood and stone would be nearly, or quite, as expensive as the deep curtain wall now proposed) the bridge cannot, in the face of the facts above quoted, be considered safe; *with* either of these additions it will have cost more than if built on wells 40 feet deep without a flooring, as originally proposed by Mr. Campbell."

No decision has been come to at present upon the measures to be adopted; but I hope at a future time to complete this paper by giving the subsequent proceedings in the case, and the results of the remedies which may be applied to the evils that have shown themselves.

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[*] I doubt it. I think the loose brick, which is free to fall down and fill up the sand as it is undermined or sucked away, would be far preferable to the solid masonry flooring proposed, and which would certainly crack when undermined from irregular settlement. The brick slag should be in large masses to prevent its being swept away, and a rough timber grating over it might perhaps be advisable for the same purpose.—[

Postscript.—Since the greater part of this paper was written, several pieces of the flooring have fallen in, having been undermined by the sand being washed out between the curtain wells. In one spot at least there appears to have been a regular stream flowing through *under* the flooring, from the upper to the lower side of the bridge. The anticipations expressed by Major Laughton in 1856, by Mr. Campbell in 1860, and by myself in 1865, have been fulfilled.

R. G. E.

Memorandum by the Superintending Engineer.

I have not been long enough in this circle of Superintendence to have acquired much personal knowledge of the conditions of the Markunda river, and the experience of one comparatively scanty rainy season cannot be considered as full data.

But however applicable the system of shallow foundations, with protective pavements and curtains, may have proved in the Madras Presidency, there has not been as yet, that I have seen, any record to show that General Cotton has considered this system to be applicable to bridges over rivers of great slope, in very light or sandy soils; and which, in Northern India, are further subject to sudden and violent floods, causing a velocity much in excess of the velocity as calculated from the slopes of the beds.

It is further clear that the liability to cutting under the bays of a bridge is much greater than in the case of dams and weirs, so that the latter cannot be accepted as a guide to the former.

The system of shallow foundations was introduced into the N. W. Provinces about sixteen years ago; and I was, I believe, one of the first to take up the idea in its experimental application to bridges. These experiments were limited to drain bridges of two or three arches, each under 20 feet span, including some long and low viaducts with arches of 10 or 15 feet span, with the prescribed protective pavements and curtains, and always with the addition of enrockments or tail pieces below bridge, in cases of much velocity. The conclusion to which these cases have led me is that the system of shallow foundations, with its adjuncts, will generally be sufficient for drain bridges in moderately firm soil, without much slope, supposing the whole to be under periodical supervision.

But the same experience, combined with later inspections of large bridges in sand or sandy soil within the N. W. Provinces and the Punjab, has convinced me that there must generally be true economy in such cases, by sinking the foundations proper, *i. e.*, those under the piers, abutments, and even wing walls, as far as they can be driven without extraordinary exertions, and under no other limit, short of 40 feet, which will in almost all cases be deep enough to be beyond the action of the water, with sufficient lateral pressure on the wells or blocks, to support the bridge. The value of this support will of course be greater in proportion to the advisability of dividing the total weight over many lines of support, but in this consideration the question of economy, as well as of waterway, will enter largely.

Under any circumstances, the foundations should evidently go deeper than the possible action of the water.

Pavements, with curtains of more or less depth, are always useful in cases of considerable velocity to equalize the action of the stream through the bays of a bridge, and I have always found enrockments or tailpieces to be much more valuable than seems to be generally supposed. They prevent serious injury during the floods of one season, and if partially displaced, they serve as a warning to adopt further measures.

But curtain walls cannot be used in all situations. Such curtains imply a stoppage of the water below the river bed, and it follows that any undercurrent filtering through sand, must be forced either above or below the curtain. The former would be inconvenient as raising the head of water, and the latter would be fatal both to pavements and curtains.

Against the system of shallow foundations, with their adjuncts, in sandy soil, is the clear fact that the least derangement, causing a movement in such soil, must upset all previous calculations, and there is no saying when sand, once in movement, may stop.

A large bridge is I believe the last kind of structure to be considered in the most economical point of view, so far as the foundations under piers and abutments are concerned. Further, the cost of pavements, curtains, and tail pieces, with their after repairs, will I think seldom leave much in favor of shallow foundations, as compared with deep foundations in the first instance, which do not require all these adjuncts.

The case of the large Markunda bridge may be considered as a bold experiment, made with the special object of placing beyond doubt if possible, the economy of shallow foundations in the Punjab; but present appearances are not in favor of the theory, although the sinking of some of the pavements is doubtless partly due to the mode of construction, as carried out from motives of economy. There have also been strong symptoms of a tendency to extensive cutting below bridge, which has necessitated the proposed addition of a broad tail piece of masonry, failing the presence of stone within any reasonable distance, and this cutting is of course quite independent of the mode in which the pavements and curtains have been built, while it would always threaten shallow curtains, however well built, if allowed to go on. The foundations proper have not yet been affected, and the expense to be now incurred for further protective measures, may be fairly calculated against the expenditure saved in the first instance, by avoiding deep foundations, and in the economical construction of the pavements and curtains.

It may be remarked of the system of shallow foundations that they cannot be expected to last long, without constant or periodical repairs to the protective works.* Such protective works connected with works of irrigation in the Madras Presidency probably *pay* while they last, which is doubtless a sound calculation (so far as the Public Works Department is concerned), when capital is not immediately available for extensive works on a more permanent basis: but it seems equally evident that works of a permanent nature would *pay better*, supposing capital to be available. Expenditure on original works is generally a more prominent matter, and more apt to catch general attention than a succession of expenditure on repairs, and we have to consider that in many parts of Northern India, the means of periodical repairs are comparatively expensive from the scarcity of wood and stone.

The quotations made by the Executive Engineer from the opinions given by several Engineer Officers, and from the orders issued by Government on the subject of the Markunda bridge, all lead to the conclusion that a question of admitted difficulty, has been put to the test in a form which must go far to prove the advisability or otherwise of shallow foundations (with their adjuncts) in Northern India. There seems to be nothing in any of the opinions or orders given, to be taken as a positive expression of opinion on the subject, and nothing can be better under all circumstances than the tentative process now in course.

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* And probably, constant attention to the state of the river bed, so that accumulations of silt formed during the rains, and causing an irregular current through the bays, should be regularly cleared away in the cold weather.—[

It is further due to Colonel Yule's suggestions, to state that his suggestions have not been fully carried out, and that the substitution of inferior and more economical materials in the pavements, &c.,* appear to have been altogether due to the Executive Engineer of the time being. So far, the test, as yet, has only been a partial one.

J. D. C.

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* With the omission of a row of wells.

No. CXIX.

THE GREAT TRIGONOMETRICAL SURVEY OF INDIA.

(4TH ARTICLE.)

Compiled from the Annual Reports of MAJOR-GENERAL SIR ANDREW WAUGH, R.E., F.R.S., *late Surveyor General of India.* BY H. DUHAN, ESQ., *Personal Assistant to Surveyor General.*

THE next party to be reported on is the *Madras Topographical Survey* party, under Captain Saxton. Although the tract inhabited by the Gonds and other aboriginal tribes, extending from near the Coromandel coast to the Nagpore territories, is not of much value to the revenues of the British Government, and is peculiarly difficult to survey on account of the physical features of the country, as well as its insalubrious character, still a general survey of the whole tract on a moderate scale appeared an important requisite for political and military purposes, and the general objects of Government; accordingly arrangements were made for a scientific survey of Ungool and the surrounding country, work being commenced at the extremity of the South Parasnath Series near Balasore, which enabled Captain Saxton to commence with data furnished by the G. T. Survey, thereby securing accuracy and saving much time and trouble in measuring base lines and determining a point of departure.

Captain Saxton reported that the whole country was jungle, but the ranges appeared favorable for triangulation, which the party proceeded to lay out in advance. A little after the middle of December, sickness commenced; and shortly afterwards, increased to an alarming extent. Captain Saxton, and two of his assistants, were compelled to proceed to Cuttack for medical aid, and the whole party was in fact disorganized; the season's operations proving thus nearly a failure.

Notwithstanding the anxiety which these untoward circumstances occasioned, the Surveyor General felt reluctant to declare the undertaking impracticable. The unhealthiness of the climate in all December being clearly demonstrated, orders were issued that the party should not reach their ground before 1st January. On the other hand, the climate becomes dangerous by the middle of March. The season being thus limited, it was a great object to strengthen the party as much as possible, which having been done, the results of the next two seasons were more satisfactory. The hill tract under survey was reported as being covered with dense and unwholesome forests, hardly animated at long and distant intervals by a sparse population of aboriginal tribes in the lowest stage of barbarism. The area surveyed was 2,515 square miles, of which 565 were on the one inch, the remainder on the half-inch scale.

In 1849, immediately after the conclusion of the Punjab war, a survey of the neighbourhood of Peshawur was commenced at the desire of the Military authorities by Lieuts. Garnett and Walker, Engineers, which was gradually extended so as to include a *Military Survey of the Northern Frontier Trans-Indus*, the operations being placed under the control of the Surveyor General. 400 square miles were completed by June 1849, when Lieut. Garnett was sent to Kohat, and the work was continued by Lieut. Walker* alone. That Officer adopted a scale of an inch to the mile, except in the vicinity of the city of Peshawur, where the work was taken upon the 2 inch scale. The instrumental equipment was unfortunately of a small kind, as instruments of the highest power could not have been employed or carried in such a disturbed country.

Operations had been commenced by measuring a base line of 2½ miles in length, and triangulating therefrom. The sides of the triangles varied in length from 4 to 16 miles, their general average being 6 miles. By December 1849, Lieut. Walker had completed the survey of the ground south of the Caubul river, and east of the city as far as Naoshera. He was then directed to accompany the field force proceeding to Eusoofzai, during which time the survey was of necessity discontinued.

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* Now Lieut.-Col. Walker, R.E., Superintendent G. T. Survey, and Officiating Surveyor General.

Immediately after the close of the military operations, a survey was ordered of the valley of Loondkhwar in Eusoofzai. Having no time to carry up the triangulation from Naoshera, a new base was measured, and a survey made of 150 square miles, on the scale of 2 inches to the mile. This being effected, Lieut. Walker triangulated backwards to his former network, and found a difference of 2 yards per mile in the common side of junction. This is a degree of error to which minor triangulation depending on bases measured with common chains at different seasons, carried on with small theodolites reading to minutes, and with indifferently marked signals, seems to be fully liable, and which can only be avoided by the rigorous precautions of the G. T. Survey system. About the middle of May, Lieut. Walker returned to cantonments for the recess, during which a map was made of all the country that had been surveyed, and a copy forwarded to the Board of Administration at Lahore.

Ill-health prevented his returning into the district before the end of November, about which time he recommenced operations from the vicinity of his base line in Loondkhwar, proceeding east to the Indus, thence south to Attock and finally west, until a junction was again formed with the former triangulation terminating at Naoshera. To test the accuracy of these operations he measured a third base near the banks of the Indus, and found a discrepancy of a yard per mile. The work was improved by the grant of additional establishment, enabling the stations to be marked by pillars, but the telescopic power of the theodolite was so feeble, that opaque signals were seen with great difficulty, and the accuracy attainable was thereby greatly limited.

The area surveyed up to the end of season 1850-51 was reckoned about 3,100 square miles, of which nearly 2,000 belong to the British Government, and the remaining 1,100 to independent Pathans. This last portion, though hostile, was surveyed with nearly as much accuracy as the former, and on the same scale. The cost was about Rs. 3¼ per square mile. By September 1851, a map was completed of the whole valley of Peshawur, including Eusoofzai, and as much as Lieut. Walker could get access to, or see distinctly, to the north and west beyond the frontier.

His adventures while surveying among hostile tribes were of a most interesting description, and often attended with great risk. He had frequently to obtain access to his stations, by causing diversions to draw off attention for a limited time, during which he had to take his observations and then ride hard for life. By tact and management, as well as cultivating friendly relations with the Chiefs, he succeeded in conducting his work without collisions, and with only a single accident, on which occasion his native groom was killed.

Having been supplied with more powerful instruments, the survey was continued during the following season, being first connected by a series of triangles with the Base at Attock, so as to form part of the G. T. Survey. Lieutenant Walker's Khattak Hill Series orginates from the side, Attok to Pir Subak, of the G. T. Survey, and was skilfully conducted to Kohat. Owing to the dangerous character of the Afridi tribes, his scope of selection was limited. For the same reason the connection of Kohat and Peshawur, though only 30 miles apart, was of necessity dependent on a series of triangles nearly 150 miles in circuit. These deviations from a direct course were unavoidable, and are mentioned only as illustrating the peculiar difficulties of the survey.

During the season 1852-53, Lieut. Walker completed the survey of the whole highland frontier Trans-Indus, embracing the Southern Khattaks and Bunnoo, besides extending a reconnoissance into the plains of the Deraját, as far as Dera Ishmael Khan. In the progress of his operations, he took many observations for fixing the chief visible points of the ranges beyond our boundary. Fourteen peaks were thus determined, extending over a distance of 50 miles along the summit of Safed Koh, or the White Mountains, which constitute the watershed between the Cabool and Koorum rivers. Thus, and with the assistance of native information, he made a tolerable map of the country beyond our boundary, as far west as 69½ of longitude.

The total area of British territory thus brought under survey, exceeds 6,000 square miles; and the survey has been of the highest utility in the subsequent numerous military operations against the frontier tribes.

In the season of 1853-54, the Surveyor General measured the Base

Line near Attok in the plains of Chuch. Subsequently, the Base Line apparatus was carefully transported to Karachi, where in the season following, the Karachi Base Line was measured. These two Base Lines complete the linear verifications required for the great quadrilateral figure of Sironj, Dehra, Attok and Karachi. The results of the verification of the important series of triangles terminated by these bases are given below; and considering the extent of the triangulation they must be considered satisfactory.

Error of North-west Himalaya Series at Chuch Base line, (the value by triangulation being in excess,) 1·262 feet or 0·30 inches per mile.

Error of Great Longitudinal Series at the Karachi Base line, (the value by triangulation being in defect,) 1·165 feet or 0·17 inches per mile.

During the previous year, Major (then Lieut.) Tennant, R.E., had been directed to build an observatory on a favorable site selected for the purpose near Karachi, in order to verify by celestial observations the value of Latitude and Azimuth brought down from Sironj by the Great Longitudinal Series. One of the great Astronomical Circles employed on the Great Arc was used for this purpose. The results were as follows:—

		Latitude.		
At Karachi observatory,	by celestial observation,	94°	49′	49″·273
„	by Great Longitudinal Series,	94	49	50″·155
	Discrepancy,	0	0	0″·882
		Azimuth.		
At Karachi observatory,	by celestial observation,	179°	59′	57″·425
„	by Great Longitudinal Series,	179	59	57″·737
	Discrepancy,	0	0	0·″312

This officer also successfully carried out a series of Tide Observations with a self-registering gauge, for the purpose of determining the datum at Karachi for the survey heights.

During 1858, arrangements were made for carrying up a special series of *Levelling Operations* from the tide gauge at Karachi to the Chuch Base, for the purpose of determining accurately the height above the sea level of stations in the interior, and furnishing a precise datum for the mountain operations. Hitherto the heights determined by the G. T. Survey of India have been deduced entirely by means of reciprocal vertical angles, except in the case of short levelled lines necessary to connect the tide gauges with the nearest stations of the triangulation. Since the improvements introduced in the process of Trigonometrical levelling, the results have proved highly satisfactory, especially in hilly tracts, where, from the nature of the circumstances, spirit levelling is inadmissible, and the Trigonometrical process by reciprocal verticals can be practised under great advantages. In the plains, however, the case is reversed, and on account of the uncertainties of terrestrial refraction in rays grazing so near the surface, great anxiety was felt lest error should accumulate in such long lines of operations, as the survey had to deal with in the plains of Northern Hindostan. The very accurate results obtained by the Trigonometrical levelling have already been remarked, (see page 104,) but they nevertheless appeared to the Surveyor General not sufficiently in keeping with the wonderful precision attainable in all the other results of the survey. Much depends on an accurate determination of the height of the base lines, in regard to their reduction to the sea level, which affects the lengths of the arcs and all the linear distances of the Survey. It was also a matter of great interest to bring up an accurate datum from the sea to the Himalayas, in connection with the determination of the heights of those stupendous peaks. It was further a matter of importance to furnish an accurate datum to the Canal Departments of Sind, Punjab and the N. W. Provinces; and to connect their levelling results, and those of the Railway Department, with our own. For all these reasons, it was determined to carry a line of levels up the valley of the Indus with the greatest precision attainable, and with all due attention to the extraordinary refinements usually practised in Trigonometrical operations, though not hitherto attempted in ordinary levelling. The great distance to be levelled, and absence of the means of verification at the termination, rendered unusual precautions indispensable.

The first part of the Indus Series crosses a hilly tract, and a similar highland region occurs before the triangulation terminates at the Chuch Base, a distance of 960 miles. With these exceptions, for the greater part of its course the series traverses, by the aid of towers, a flat alluvial plain. The party under Major Walker was equipped with

THE GREAT TRIGONOMETRICAL SURVEY.

Towers erected for the principal Triangulation in the Plains.

Fig. 2.

Transverse Section.

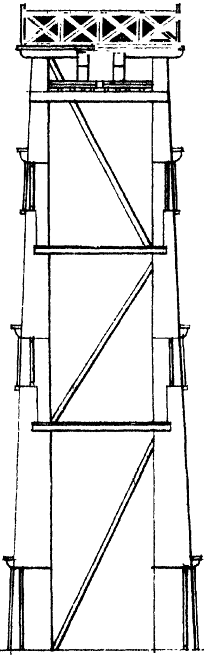


Fig. 1.

Elevation.

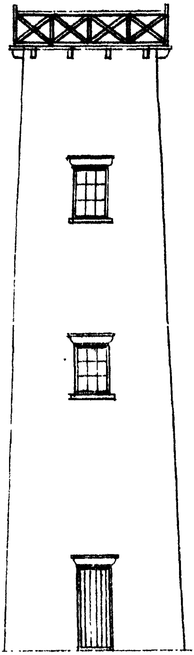


Fig. 3

Ground Plan

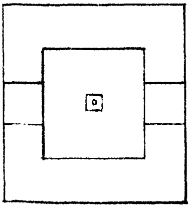


Fig. 4.

Plan of 1st Floor

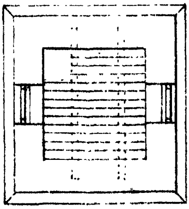
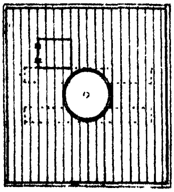


Fig. 5.

Plan of Platform



three first-class standard levels by Troughton and Simms, transferred for this purpose by the Punjab Canal Department. These had powers averaging 42, and a focal length of 21 inches. Graduated scales were attached, so that the level errors could be recorded and corrected for, in the same way as in Astronomical observations. It is humanly speaking impossible to level an instrument practically without some residual errors, however small, but it is practicable to note the errors and compute the corrections due to them, a process by which accumulation of small errors is prevented. The staves were made for the special purpose in the Mathematical Instrument Department, graduated on both faces in a peculiar manner, and with every precaution as to conformity with the unit of measure of the Indian Survey. For the subsequent verification of the unit, a standard bar was supplied as a provision against accident or change in the staves.

As a precaution against the intrusion of gross errors and to lessen the anxiety which a single leveller must experience if he works alone for months, without knowing whether his results are accurate or not, it was determined that three observers should level along the same pins one after the other, using each his own instrument and staves. Thus, any error could at once be detected and rectified on the spot, and the work was thus subjected to check at each step of its progress.

The operations commenced at Sojra tower, and the levelling was carried upwards in a continuous rise. After proceeding some distance a personal error was discovered of a very minute but constant character, whereby the results of the three observers diverged from each other. Though the differences were extremely small, their constant character gave reason for anxiety in regard to their accumulating tendency on a long line of 960 miles. This led to a long discussion, which ended in the adoption of an alternating system of observation, whereby the benefits of a circuit system were obtained, and many sources of instrumental error counterbalanced. By these means, the differences between observers were much reduced, and in some cases counteracted. The work beginning at early morning at the lowest temperature and maximum amount of aqueous vapour, it was evident that as the temperature rose the air became drier, and the refraction constantly diminished. Though the difference taking place in the interval between a back and forward sight, was extremely small, and its effect almost insensible on the third place of decimals of a foot, still the tendency being constant, its accumulative effect might be dreaded on so long a line. For these reasons the staves were observed, and the observations repeated in an alternate manner at each station, as also at alternate stations. Similar precautions against the accumulation of minute quantities were taken in the manipulation of the instruments. In order also to introduce the highest degree of refinement the work was susceptible of, new levels, freely mounted and supported at the two points of least flexure, and covered with glass cases, as a protection from currents of air, were prepared in the Mathematical Instrument Workshops.

In the course of these levelling operations, numerous bench-marks were buried at important places, seven canal and railway bench-marks were connected and nearly 200 mile-stones marked. The connection with the Canal and Railway affords a check by circuit. For example, Major Walker's levels from Shikarpore to Kotree *viâ* Larkhana and Sehwan, with the Canal levels *viâ* Sakkar and Hydrabad, close with a discrepancy of only 0·09 foot in 560 miles.

The result obtained from this series of levelling operations is most satisfactory, and indeed, may be pronounced a triumphant feat; as will be seen from the following statement, viz :—

1.	From Karachi sea level to Chuch Base (Spirit levelling), ..	960	miles.
2.	N. West Himalaya Series, (Chuch to Banog,) Trigonometrical mountain levelling, ...	412·8	„
3.	Great Arc Series, from Banog to Sironj, ...	445·0	„
4.	Great Longitudinal Series, Sironj to Karachi sea level, ...	678·4	„
	Total length of circuit,	2496·2	

This circuit of levelling, chiefly Trigonometrical, and embracing 210 miles of Trigonometrical levelling over plains, closes with a discrepancy of 0·753 of a foot, giving a rate of only $\frac{3}{10000}$ of a foot per mile.

On the Great Indus Series there were two independent levelling operations, viz.: —1st, The Trigonometrical levelling along the series which is 710 miles in length, of which 384 are unfavorable plain country; and, 2nd, Spirit levelling over a circuitous route of 960 miles. The comparisons between the two results at the points of connection along the series are highly satisfactory, and the ultimate results most gratifying, as will be seen from the following statement:—

	Feet.
Height of west end Chuch Base, by Spirit levelling, brought up from the sea level at Karachi, ...	1014·603
Height of same point brought up by Trigonometrical levelling, from same datum, ...	1012·30
Difference between Spirit and Trigonometrical levelling,	2·303

This gives a rate of error on 700 miles of ·003 of a foot per mile, which is wonderfully accurate for Trigonometrical levelling, especially over a tract of 384 miles of unfavorable country.

The next series to be reported on is the *Kashmir Series*. After the completion of the Karachi Base, Captain Montgomerie R.E., was deputed on this duty, and commenced Trigonometrical operations on the Kashmir meridian. The first season's triangulation having been laid out across two ridges of the snowy mountains, and advanced into the heart of Kashmir, the Surveyor General proceeded to organize arrangements for the Topographical Survey, which was to be based on this triangulation. On account of the small establishment at disposal, the difficulty of obtaining Uncovenanted Assistants, owing to the competition of other departments of the State, the length of time consumed in training new hands, and the difficulty of retaining them when trained, application was made for three or four young Officers of the Quarter-Master General's Department, to survey during the summer. Three officers, viz., Captains P. Lumsden, C. C. Johnson, and G. Allgood were accordingly temporarily transferred. Lieut. Elliott Brownlow of Engineers, with two assistants from other parties, were also allotted to the mountain survey. By this means the Trigonometrical establishment was strengthened sufficiently to advance the Great Series towards Thibet, and at the same time cover the area to be surveyed with points of reference for the topographical operations.

The system of survey adopted was that described in the Topographical instructions for the Department. The advantage of this system in a country like India, especially in the hilly and mountainous tracts is, that officers with a moderate previous knowledge of military drawing can readily be trained to fill up the triangles; and the work proceeds rapidly, producing a complete and valuable map, with the topographical features accurately delineated at small expense.

The three Assistants Quarter-Master General being wholly untrained to the rigorous system of surveying required, had first to be instructed; but were after a moderate probation able to proceed independently, and by the end of the season had accomplished a fair share of excellent work. For the ensuing season of 1857, it was fully expected that these three officers would have been again available. Unfortunately the exigencies of the service did not admit of this, and their previous season's training was thus lost to the survey.

The arrangements made for the prosecution of the Topographical survey having thus broken down, the whole business of training and instruction had to be recommenced *de novo*. Three other officers with the requisite qualifications were selected, viz., Captain H. H. Godwin-Austen, H. M.'s 24th Foot, Lieut. A. B. Melville, 67th N. I., and Ensign W. G. Murray, 24th N. I. These officers speedily learned their duty, and did excellent service. The strength of the Kashmir party was also increased by Lieut. Basevi of Engineers, and Assistants from other parties being transferred for the summer season.

Neither the physical character of the country, nor the constant task of training new hands formed the chief difficulty of the survey conducted in a foreign territory, and which at no time could be expected to be agreeable to the Ruler, his officials, and people. To them the influx of a considerable body of surveyors, spread over the country, however orderly and well conducted, must bear the aspect of intrusion. Captain Montgomerie had some difficulty in maintaining amicable relations with the Court, and his difficulties were enhanced by the Military Rebellion of 1857, during the whole of which excited period the party continued its peaceful and useful labors without cessation, and with only one serious interruption.

The character of a Trigonometrical survey demands that the stations shall be fixed on the highest summits, or on points commanding extensive views, and it is requisite that an adequate number of good observations shall be taken, which usually occupies several days. To accomplish this task, not only the observers, but the signal men (natives), must encamp at or near the stations. The heights of some of the peaks ascended on the Punjab range were Moolee station, 14,952 feet; and Ahertatopa station, 13,042 feet; and to the north of Kashmir, Haramook, 16,015 feet. Among the highest elevations visited in Thibet were the principal stations of Shimshak and Shunika, 18,417 and 18,224 feet, respectively. The difficulty of obtaining supplies and firewood at such elevations may be imagined, yet they were every day occurrences. Out of sixteen principal stations in Thibet, fourteen exceeded 15,000 feet in height.

Although the splendid climate of Kashmir, added to the special interest attaching to the country and the unexplored tracts adjoining, made the survey deservedly a great attraction, still the exposure of surveying in such a country is very trying to the constitution, and many persons suffered greatly. The lower valleys are very hot, and the solar radiation on the hill sides is very powerful. The labor of climbing to great elevations has often been noticed by explorers; the surveyor, however, arriving heated by physical exertion at great elevations, has to stand on ridges or peaks, exposed to strong cold winds, while he is observing angles or sketching the ground.

The whole mountain tract south of Kashmir proper was completely triangulated and topographically surveyed. In 1859, the triangulation was satisfactorily advanced in Thibet, but the Topographical operations made slower progress than usual, owing to the smallness of the establishment the Surveyor General was able to devote to that work. The work effected may be briefly summarized as follows:—

1st. Area triangulated from commencement of survey to 1859, about 50,000 square miles, (nearly equal to the area of England,) five years.

2nd. Area topographically surveyed in four years, about 23,000 square miles.

3rd. Cost per square mile, Rs. 4-5-2.

These results are highly satisfactory in quantity, quality, and cost.

The Coast Series is a most important work, as it connects the metropolis of India with the Madras Observatory, which is the origin in Longitude of the Survey of India. This operation also defines the coast. Unfortunately, however, the triangulation traverses a country presenting formidable difficulties, among which, the baneful climate may be reckoned the worst. The work was commenced at the Calcutta Base by the late Captain Thorold Hill, who was succeeded by Mr. Clarkson and Mr. Peyton. The obstructions presented by the climate and other difficulties were so great that the progress had been slow, and the cost correspondingly high. The parties had been annually decimated by sickness and driven thereby from the field. But the work was nevertheless, with singular constancy and perseverance, gallantly resumed, season by season, until by slow degrees it nearly reached Cuttack.

The Rahoon Meridional Series commenced in 1852, was necessarily suspended during the two following seasons, owing to the party being employed at the measurement of the two Base Lines. Work was shortly after resumed, and the series progressed satisfactorily. The party after the conclusion of the season's work in 1857, on returning to recess quarters, passed through Delhi and Meerut only a few days before the out-break of the mutiny, thus narrowly escaping destruction. In 1857-58, the country south-west of Delhi, through which the series passed, was so disturbed that operations could not with any regard to safety be resumed. Next year the country still being unsettled, the party was transferred to the Gurhagurh meridian, under Major Tennant.

The Gurhagurh Series was undertaken to lay down Ferozepore, and furnish fixed points for the incorporation of the Revenue Survey with the general map of the Punjab. The season proved unfavorable, and but little final work was done; but good progress was made in 1859-60 by Mr. Shelverton, who succeeded to the charge of the series, on Major Tennant's appointment to be Astronomer at Madras. Lieut. Herschel of Engineers, was appointed to fill Major Tennant's vacancy.

Mr. Nicholson's health having succumbed to the baneful climate of Assam, Mr. Lane was deputed to succeed him in the charge of the *Assam Series.* He pushed forward the work with great energy, accomplishing an excellent season's progress; but the mutiny having broken out, his party was in some danger from roving bands of mutineers, chiefly of the 34th Native Infantry. In the seasons subsequent to 1857, the progress of this work diminished, owing to the difficult and unhealthy character of the country, and its destructive climate.

The next Trigonometrical operations to be reported on, are those conducted in the Bombay Presidency. *The Bombay Trigonometrical Party,* under Captain D. G. Nasmyth, R.E., had been employed south of the Great Longitudinal Series in triangulating Goojerat, Katyawar, and Cutch, and connecting the operations with Sind. Crossing the

Runn of Cutch and the little desert, the nature of the country presented obstacles of the most formidable character, as well in regard to provisions, water and travelling requisites, as in finding suitable sites for towers, and the materials for their construction. The observations also from atmospheric vapour and mirage, were rendered peculiarly difficult and harrassing. The whole tract of country embraced by Katyawar and Cutch was fully triangulated and prepared for Topographical Survey. The numerous series into which this triangulation is divided, close most satisfactorily, showing extreme accuracy of observation, beyond what could have been expected from an 18-inch and 12-inch instrument.

Captain Nasmyth proceeded to England on furlough and was succeeded by Lieut. Haig, R.E., who was employed in the ensuing season in completing the Gogo Series, and forming a connection between the Aboo and Singi Meridional Series.

It is now necessary to summarize the proceedings of the various *Topographical* parties. Of these, the Kashmir Series has already been reported on in connection with the Trigonometrical operations under Captain Montgomerie.

Captain D. G. Robinson's survey of Jhelam and Rawul Pindee is second to none in importance, or in the excellence of its results, and the interest attaching to the locality. This great work was commenced by Captain Robinson at the close of the year 1851, and the field work was brought to a successful conclusion early in 1859. The area comprised in this survey amounts to 10,554 square miles, so that the rate of progress has been 1,319 square miles per season. The progress would have been more rapid but for several retarding causes. The cost of the eight field seasons amounts to Rs. 1,93,465-15-10, which, divided by the area, gives Rs. 18-15-2 per square mile, for the rate of the field-work.

The scene of this survey is of great interest and importance in a classical, military, geological and engineering point of view. The locality is rendered memorable as the scene of Alexander the Great's exploits, and as embracing the line of operations by which India has been invaded from the time of Alexander to that of Nadir Shah and Ahmud Shah Abdalli. It abounds in strong positions, and an elaborate and accurate map of this part of the country is therefore of great im-

NAWAB SALAR JUNG BAHADUR

portance in a strategic point of view. To the geologist it is of importance as containing the saliferous strata of the Salt range, and various formations of great interest and curiosity. In an engineering point of view, the utility of an accurate survey is manifest, and Captain Robinson's results have proved useful in facilitating the operations of the Great Road.

After the measurement of the Chuch Base, Mr. Mulheran an experienced surveyor of the department, assisted by Mr. Johnson, was deputed to finish a small portion of the great snowy range, lying between the heads of the Baspa and Ganges rivers, including the Nela Pass, which had not been travelled by Europeans or natives for many years, owing to the danger attending the crossing of the lofty and difficult part of the range. The Nela station is 19,086 feet high, and on account of its southern aspect and consequently greater depth of snow, the ascent is a more difficult achievement than an ascent to a similar altitude on the north side of the Himalaya. Mr. Johnson surveyed all the difficult ground at the head of the Baspa and Nela pass, as well as from Nilang to the Jala Kanta pass; while Mr. Mulheran finished the difficult ground at the head of the Charang, Nisang and Rishi Dogri, in Bissahir, east of the Sutlej, and continuous with Chinese Tartary. After this feat, the party was transferred under Captain Montgomerie to Kashmir, and Mr. Mulheran proceeded to organize the *Hydrabad Topographical Survey*. Mr. Mulheran's superintendence of this Survey proved successful, and justifies the expectation that the remaining portion of this survey, which embraces no less than 95,000 square miles of country, or an area larger than Great Britain will be finished in a moderate time.

In the year 1858, the Deputy Surveyor General applied for Trigonometrical points on which to base the Nagpore Revenue Survey. The Great Trigonometrical Survey not having been extended over that part of the country, Mr. Mulheran was deputed to carry a branch Series from the Great Arc to Nagpore.

(*To be continued.*)

Correspondence

THE Editor acknowledges, with thanks, the receipt of the following papers:—The Aden Tanks—Roads in Coorg—The Hurroo Bridge—Breach of the Coleroon Anicut—Manufacture of Irrigation Pipes—Practical Suggestions in Road-making—River Works on the Gogra—Karwar Harbour Works—Waterway of the Sye Bridge.

IRON TIE-BARS FOR ROOFS.

To the Editor.

DEAR SIR,—Could you find room in your next issue for the following remarks in reply to J. H. P.'s letter in No. 10.

1. It does not seem to me to be singular that the value $\theta = 0$, should give the maximum horizontal thrust. It merely shows that the horizontal thrust, expressed as a function of the variable θ, is a maximum when $\theta = 0$; or in other language, that the point of rupture is at the crown.

2. I do not take friction into account any more than J. H. P. does cohesion. It follows necessarily from this, that the resultant of the two forces applied to the half arch (its own weight and the horizontal thrust) must act at right angles to the joint. For if it did not, the resultant could be resolved into two forces—one acting in the direction of the tangent would be supported by the reaction of the joint; the other parallel to the joint, unless counteracted by friction (which I do not take into consideration), would cause the failure of the arch by sliding along the polished voussoir.

3. Rankine (Applied Mechanics, page 204) determines the horizontal thrust exactly as I have done. He says: "*when the point of rupture is the crown of the arch . . . . . . it has already been shown that . . . .*

$$H_0 = p_0 \cdot r_0 \cdot$$

p_0 . *being the intensity of the vertical load, and* r_0 *the radius of curvature.*"

I obtain the same result by finding the value of the resulting vanishing fraction. But the principle is exactly the same; and if Rankine is wrong, I am quite content to be wrong also.

4. J. H. P.'s Formula (although no doubt perfectly correct on the supposition that the arch turns on the edges of the voussoirs) is quite inapplicable in practice, from the enormous labor of calculation it entails. Petit has calculated Tables for J. H. P.'s formula, by means of which I have been able to compare his results with mine; and in every case my formula gives the safer result. These Tables of Petit are now very scarce, and without them J. H. P.'s formula is useless.

5. My formula is as mathematically correct as J. H. P.'s; and has the great advantage of giving a safer result, and of being readily applicable in practice.

6. Should you wish it,* I can give you a comparative statement of the results of the two formulæ, as applied to roofs as usually constructed.

Yours truly,

A.

CAMP, BAGNEE,
1st May, 1866.

The above was accidentally delayed in transit.—[ED.]

THE "COMPTAGE AMBULANT."

SIR,—Your correspondent, in the last number of Professional Papers, is perfectly right.

The mistake, a clerical error, occurs in putting the formula $C = O + M' - M''$ into words.

When printing the errata to this volume, will you kindly enter at page 69, line 5; *read*, "That when the traffic is the same up and down the road, it is equal to the number of carts met by the observer going in his opposite direction, added to the number which pass him going in the same direction and diminished by the number of carts going in the same direction which he passes:" *instead of*, "That when the traffic is the same up and down the road, it is equal to the number of carts met by the observer going in his opposite direction, added to the number he passes going in the same direction, and diminished by the number of carts going in the same direction which pass him.

W. J. L.'s letter affords numerical proof of the correctness of the formula.

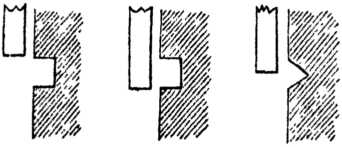
Yours faithfully,

A. J. HUGHES.

HIMALAYA CLUB,
29th June, 1866.

NOTES ON LEVELLING.

DEAR SIR,—K. C. L. in his excellent remarks on Levelling and Bench-marks in your February number, recommends the broad arrow and bar used by the Ordnance Survey, but he does not state what portion of the horizontal bar forms the bench-mark. The groove or bar is perhaps half an inch to an inch wide, and the marginal sketches show that there are three distinct positions in which the bottom of the staff may be held, making a considerable difference in its level. It would therefore add much to the value of K. C. L.'s paper if he would clear up the point.



Yours truly,

W. H. M.

8th May, 1866.

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* Yes; let us have it.—[ED.]

A SUGGESTION.

My Dear Sir,—There are few men in the P. W. Department who have not, at some time or other, suffered in taking over a new division, from the difficulty of finding out the previous history of the large works which have been some time in hand. The relieved officer's Memo. of works in hand is seldom of much use, except for just the current arrangements.

In my own case, I have just taken over a division in which there are several heavy works, about which correspondence has been going on for very many years, and actual work some five or six years. Alterations have been now and again ordered, and many revised estimates submitted, and generally each work has been carried on on the *coming* estimate, so that no one specification has been followed throughout. Just lately some peculiar departures from my specification have come to light, and down comes Government and calls out, who did this, and why did he do it ? Now, to make myself acquainted with the works, and answer such questions as the above, I have to hunt up correspondence and progress reports for many years, and then I can't do it. I shall leave the division again soon, and my successor will have all the trouble over again.

Now all this trouble and confusion might be remedied, and also any unauthorised departure from sanctioned specification much checked, if every Executive Engineer had to keep a running note or precis of all correspondence on all large works separate for each, in something like the accompanying form.

Abstract of Correspondence, &c., on ______________________

Letters received and despatched.				Abstract of Contents.	Contemporary memo. of state of work, orders issued, accidents, &c., &c.
Date.	No.	From	To		

The posting up should be done, I think, by the Executive Engineer himself, and he should enter a work in the book when it had been six months, say, under discussion, posting up the back six months at once.

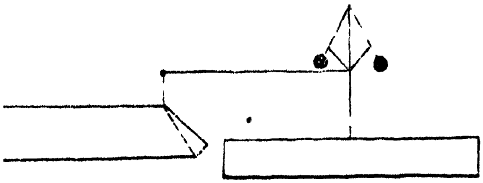
I think the advantage of such a record to every one concerned, will be readily allowed, and I don't think the labor would be a heavy addition to any one. Superintending Engineers would for their own interest see that it was kept up, and each Executive might feel that others were doing the same, so that he would get the benefit when he exchanged. Perhaps some of your correspondents might improve on my idea, and suggest how it could be brought into practice.

Yours sincerely,

A. M. B.

To the Editor.

SIR,—An idea struck me a day or two ago that a uniform discharge, through a pipe with varying heads of water, might be obtained by means of a small water-wheel (driven by the water as it issues through the valve), driving a governor exactly the same as a steam engine governor, so that the lower the velocity of the water the larger the orifice would be, and the greater the velocity the smaller the orifice. Will you favor me with your opinion as to whether it would be of any practical value or not?



Your obedient servant,

H. H.

Make up a model and try it. The difficulty attending the solution of this problem lies in the practical working: simplicity of construction is a *sine quâ non.*—[ED.]

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J. G. Medley, Major, R.E.,
Principal.

Roorkee, *August*, 1*st*, 1866.